Optimizing the large-scale renovation strategy

Master thesis

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Jarich (Rick) Dijkstra

Title	Optimizing the large-scale renovation strategy
External company	Witteveen+Bos Raadgevende ingenieurs B.V. Van Twickelostraat 2 Postbus 233 7400 AE Deventer
External supervisor	MSc. I. Snijders Blok
Supervisor UT Twente	Dr. F.H.J.M. Coenen
Second reader	MSc. I. Lammers
Author	Jarich (Rick) Dijkstra
Student number	s2032341
University	University of Twente
Programme	Master of Environmental and Energy Management
Contact	rickdykstra094@hotmail.com
Cover photo	Beek, 2015

PREFACE

This master thesis 'Optimizing the large-scale renovation strategy' has been written as part of the Master Environmental and Energy Management at the University of Twente. I conducted this research at the request of Witteveen+Bos Raadgevende ingenieurs B.V. I was engaged in this research from April to August, 2018. During the past five months I gained a lot of experience and knowledge with regard to the building environment.

I would like to thank Iris for her instructive guidance and for contributing to my graduation research. Furthermore, I would like to thank Koen Haans and Bert van Dorp for giving me the chance to carry out this assignment. I also wish to thank all the people from Witteveen+Bos who were involved in this research.

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Jarich (Rick) Dijkstra

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ABSTRACT

The building sector represents a large potential for energy savings and CO_2 reductions. This sector (residential and non-residential use) accounts for 30% of the global energy consumption and 25-33% of the CO_2-emissions. To limit the CO_2-emissions and realize an energy neutral building stock by 2050, a reduction in the energy demand and a transition from fossil fuels to sustainable energy sources is needed in the building sector. This research focuses on the residential building stock.

By improving the energy performance of buildings significant steps can be made in order to achieve the climate and energy targets. For new houses this transition is easier to be made. However, the real challenge lies in the renovation of existing houses. At the moment various stakeholders such as home-owners, housing corporations and municipalities struggle to renovate the existing building stock in order to improve the energy performance and reduce the energy consumption. In short, there is a lack of knowledge, building capacity and investments in order to renovate the existing housing stock in a short amount of time. Currently, the renovation pace is too low in order to reach the goals of 2050. Not only do they struggle to increase the renovation pace, reaching the targets also requires a huge investment. On top of that, renovation projects require different skills, experience and knowledge regarding technical, economic and social aspects compared to new construction projects. Although there is a great understanding of existing renovation practices, there is a lack in knowledge and insight in the various aspects which affect this decision making and how an optimal renovation strategy can be established based on this information.

Analysing and predicting the energy performance combined with energy savings of existing buildings on a large scale can aid the decision process of large-scale renovation strategies. Models can be of great use by quantifying this needed information. Witteveen+Bos is looking for such a new model that can be used in order to advise stakeholders, such as housing corporations or municipalities. This research tried to provide more insight into these aspects by answering the following research question:

How can the large-scale renovation strategy of existing houses be optimized by predicting the energy performance and proposing renovation strategies by using a model, particularly in the Netherlands?

The goal of this thesis was to give insight into how the large-scale renovation strategy can be optimized with the use of a model. This model should predict the energy performance and propose suitable large-scale renovation strategies. In order to do so, insight was needed in energy performance parameters and the large-scale renovation strategies. Although the thesis mainly focused on designing a model based on building related characteristics, insight was needed in the general renovation process. Therefore, the total spectrum regarding energy performance parameters and parameters influencing the decision-making process for an optimal large-scale renovation strategy were analysed. This was done based on the existing literature, reference projects and expert judgement.

The research shows that there is no "universal" optimal large-scale renovation strategy, which can be used to improve the entire existing housing stock. The decision-making process for choosing an optimal large-scale renovation strategy is too dependent on the characteristics of the specific situation. In any decision-making process, whether this is done by a housing corporation, municipality or a single home-owner, there is a wide variety of possible renovation strategies that can be considered and it is not easy to select the optimal one. The decision-process for renovation projects includes many bottlenecks such as changes in consumption behaviour, ability to change the appearance, building conditions, type of ownership and energy performance. The selection process of an optimal large-scale renovation strategy can be seen as a trade-off between ambitions and requirements of the relevant actors (e.g. homeowners and housing corporations), the financial investment needed and the benefits obtained from that renovation strategy, constrained by the relevant parameters.

In order to simplify and facilitate this decision-making process for stakeholders like housing corporations or municipalities, a model framework was designed. This model framework is based on the combination of various tools and models and can be seen as a decision-support instrument. The instrument can be used by Witteveen+Bos to assimilate key information of individual buildings and lift this to a larger scale (e.g. district level). In this way insight can be given in the energy performance and the possibilities of applying a large-scale renovation strategy for existing houses on a district level. This insight can be used by stakeholders like housing corporations or municipalities to facilitate the decision-making process with regard to the improvement of the existing housing stock. The advantage of the proposed model framework is that it can provide a quick analysis of the energy performance and opportunities for applying certain large-scale renovation strategies. With the use of a case study, the tools and models were tested by using three possible renovation scenarios. The case study shows that the potential for applying a large-scale renovation strategy differs, based on the building characteristics, type of housing, energy demand and performance.

Although the presented information can be of use to these stakeholders, the proposed model framework is limited to building characteristics. In practice, there are various types of ownership, household compositions and constellations of actors and initiators present and relevant in large-scale renovations. These aspects are also related to the energy performance and have to be considered in large-scale renovation projects. Integrating these household and socio-economic characteristics into the model framework could provide more insight into the possibilities for applying a large-scale renovation strategy. In addition, adding active measures into the optimization tool can give more insight into the optimal large-scale renovation strategy. Active measures such as solar PV, heat pumps and district heating are key to realizing an energy neutral housing stock. On top of that, using a life-cycle costs analysis in the model framework can provide a different financial overview. This can be used to determine an optimal renovation budget. Other aspects, such as benchmarking the results of the GIS-tool with registered data and testing the tools and models in multiple cases are important as well. This can result in a better understanding of the reliability of the designed tools and models.

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1 INTRODUCTION

1.1 Problem statement

To achieve the aim of the new climate agreement, to limit global warming to well below 2 degrees Celsius, the CO_2-emissions must be reduced drastically. In order to realize this, a reduction in the energy demand and a transition from fossil fuels to sustainable energy sources is needed. The building sector represents a large potential for energy savings and CO_2 reductions. The building sector (residential and non-residential use) accounts for 30% of the global energy consumption (figure 1.1). This sector accounts for almost two-thirds of the total greenhouse gas emissions 25-33% of black carbon emissions (IEA, 2013; 2017).

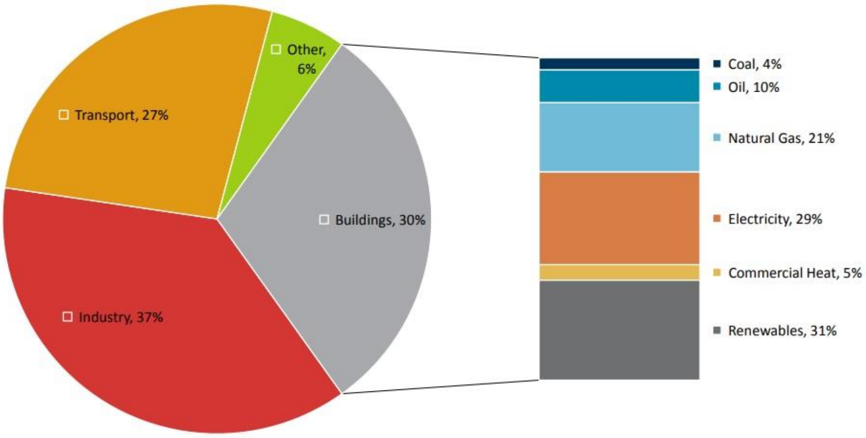

Figure 1.1 Global energy usage[1] (IEA, 2015)

By improving the energy performance of buildings significant steps can be made in order to achieve the climate and energy targets. For new houses this transition is easier to be made. However, the real challenge lies in the renovation of existing houses. The building sector is experiencing under investments in improving the energy performance of the existing building stock. Private homeowners do not invest quickly in improving their house. First of all, there are few sustainable renovation solutions available with guaranteed performance and good market conditions. This means solutions which are financeable for each target group and result in a reduced energy bill. Secondly, it is difficult to get residents' support for far-reaching renovation measures. Residents have little confidence in a guaranteed improved living experience with similar costs (Stroomversnelling, 2018). In order to stimulate the improvement of the building stock, the Energy Efficiency Directive (EED) adopted a requirement for European Member States to develop long-term renovation strategies for their national building stocks (BPIE, 2013).

The Netherlands is lacking behind in this transition as well. In households, natural gas is currently the most important form of energy for heating, hot tap water and for cooking. Natural gas accounts for 93% of the heat used in the Netherlands. The rest of this heat is supplied by the use of heat networks/district heating or other renewable sources such as solar heat, electric heat pumps and biomass (Energieonderzoek Centrum Nederland, 2017). Various international and national agreements have been made in order to make improvements and disconnect from the gas grid, such as:

- in 2050 the built environment is completely energy neutral;
- 100 Petajoules (PJ) of energy saving in the final energy consumption of the Netherlands by 2020 (Ministerie van Economische Zaken, 2016; Rijksdienst voor Ondernemend Nederland, 2017a; SER, 2013)

[1] Although the use of renewables may seem positive, most of this source comes from traditional biomass, including wood, charcoal and dung. In non-OECD countries, traditional biomass remains the largest source of energy.

In order to reach the goals of 2050, every year 170,000 homes need to be renovated, which accounts for more than 2% of the total existing housing stock in the Netherlands. At the moment this renovation process is going slow (Ecofys, 2016; Filippidou et al, 2017; Ministerie van Economische Zaken, 2016[1]).

The government continues the promotion of renovation through price incentives, subsidies, low-interest loans, information and support for innovative approaches. An active role of municipalities as facilitators at local and regional level is expected for the concrete design and improvement of the existing building stock. In addressing energy reduction, municipalities follow a large-scale, area-based renovation approach. The municipalities facilitate an integrated large-scale approach, such as facilities in the area of local heat networks, heat/cold storage and decentralized production of energy and collective neighbourhood renovation approaches (Stroomversnelling, 2018). However, the way in which these large-scale approaches are implemented in practice is often not clear (Vastgoedmarkt, 2017). Despite great ambitions to 'get rid of gas', municipalities struggle to realize district heating on a large scale in the built environment (Hendriksma, 2017; Leefomgeving, 2017). Furthermore, the strategies used by municipalities are not always effective. According to Murphy, 2016, instead of financial support, permanent instruments should be put in place to improve the energy efficiency of (private) homes. Also, stimulation tools should be smarter and more refined and more focused on actual energy consumption (Murhpy, 2016).

Even in the housing corporation sector, where sustainability is an important theme, the stated goal of an average energy label of B will not be achieved. Aedes, the national association of housing corporations, recognizes that the pace is too low to meet government targets in 2020. It is not possible to keep the rents low and at the same time invest says Tony Dijkhuizen of Aedes (Dujarding, 2016; Schilder et al, 2016). Not only do they struggle to increase the renovation pace, reaching the targets also requires a huge investment. According to Aedes, more than 108 billion euros is required to realize gas-free and CO2-neutral rental houses (NU.nl, 2018).

Besides the renovation speed, there is a lack of adequate advice and technical expertise. Renovation projects require different skills, experience and knowledge compared to new construction projects. Stakeholders such as housing corporations, project developers, home-owners and governments are trying to increase the renovation rate by formulating renovation strategies (Vringer, van Middelkoop, & Hoogervorst, 2016). A large number of measures and techniques have been or are being developed for new buildings in order to meet the current building regulations. Measures such as extreme insulation, heat pumps, solar panels and heat recovery ventilation. However, the renovation of existing houses has to cope with a number of specific preconditions, making some these measures less applicable. A direct integration of these measures for the renovation of houses could be at the expense of comfort, energy savings and economic feasibility. In addition, the wide variety of renovation measures does not provide easy decision-making process for stakeholders in the renovation process (Rijksdienst voor Ondernemend Nederland, 2009; Stroomversnelling, 2018).

In other words, there is a shortcoming in understanding the impacts of different measures and the related costs, CO_2 emissions and energy savings. The question is, what set of measures is optimal for an area-based renovation approach for the long-term, or so-called 'large-scale renovation strategy' given a certain situation (Aksoezen, Daniel, Hassler, & Kohler, 2015; Konstantinou, 2014). At present, there is no information about the potential for energy savings and possible large-scale-renovation strategies for individual houses at a district level. As a result of which stakeholders such as local authorities and housing corporations cannot properly fulfil the aforementioned renovation task. Furthermore, there is a lack of knowledge of the bottlenecks and parameters which influence the decision-making process for these stakeholders.

Analysing and predicting the energy performance combined with energy savings of existing buildings on a large scale can aid the decision process of large-scale renovation strategies. Since there is no publicly available data regarding the actual energy performance of individual houses at a large-scale, models can be of great use by quantifying this needed information. Furthermore, modelling techniques allow for a simplification of the complexities involved in the current renovation process, saving time. Witteveen+Bos is looking for such a new model that can be used in order to advise stakeholders, such as housing corporations or municipalities. This model should focus on the building related characteristics of the housing stock, and be applicable for the whole Netherlands.

1.2 Research objective and question

The objective of this research is as follows:

Give insight into how the large-scale renovation strategy of existing houses can be optimized by predicting the energy performance and proposing renovation strategies by using a model, particularly in the Netherlands.

To achieve this goal, the following research question must be answered:

How can the large-scale renovation strategy of existing houses be optimized by predicting the energy performance and proposing renovation strategies by using a model, particularly in the Netherlands?

1.3 Reading guide

The thesis is structured as follows:

In chapter 1 the problem statement is presented. This is followed by the research methodology in chapter 2. In this chapter the research questions and design is described. Furthermore, an elaboration is given how the research was research carried out.

The research consists of three parts. First, the concept regarding the energy performance of houses was analysed. This analysis is shown in chapter 3. Furthermore, the various techniques applied in literature to model the energy performance on a large-scale are shown. Energy performance parameters were drawn from this analysis. Chapter 4 includes the analysis of the various large-scale renovation strategies applied in literature and practice. In order to understand how this works on a large-scale, the renovation process for a single house was studied first. On top of that, the various parameters which influence the decision-making process for stakeholders such as housing corporations or municipalities are discussed.

Based on this literature, presented in chapter 3 and 4, a model framework was developed. This framework is based on the combination of various tools and models. How these concepts of energy performance and large-scale renovation strategies were integrated into this framework is discussed in chapter 5. This is the second part of the conducted research.

Subsequently, the developed tools and models were applied and tested in a case study, this is the third part of the research (test phase). This is described in chapter 6. This chapter discusses the test and the results. Improvements for the tools and models were drawn up on the basis of this case study.

A short discussion and conclusion regarding the research design and results can be found in chapter 10. In addition, recommendations are given regarding the proposed model framework and follow-up studies.

2 RESEARCH STRATEGY AND METHOD

In this chapter the research framework and questions are presented and explained. Per sub-question a description is given what kind of research method was used, which sources were needed and how this resulted in answer for the sub-question.

2.1 Research framework

The research framework (shown in Appendix I) gives insight into the theoretical framework, key concepts and conceptual model needed in order to form the research questions and strategy. The research objective is, or the desired result is the following: *give insight in how the large-scale renovation strategy of existing houses can be improved by predicting the energy performance and proposing renovation strategies by using a model particularly in the Netherlands.*

This insight is needed for stakeholders such as housing corporations or policymakers (e.g. municipalities) which enables them to target specific districts with an optimal large-scale renovation strategy. This model can be used as a decision support instrument by Witteveen+Bos, targeted at individual houses on a district level. The output can be used for housing corporations or municipalities in order to evaluate the impact of certain large-scale renovation strategies to improve energy performances of existing houses. By generating and visualizing suitable large-scale renovation strategies, specific insight can be given on how the energy performance of individual houses on a district level can be improved. This model has to be applicable for the whole housing stock in the Netherlands. In order for the proposed model to be repeatable, it has to use widely available open source data. The model can be seen as the research objective. Input is needed for this model, that is, the model has to predict the energy performance of houses on the district level and propose certain large-scale renovation strategies.

A conceptual model will function as the research perspective which was used to determine the relationship between large-scale renovation strategies and the improvement of the energy performance. This analysis was based on theory regarding energy performances of houses and large-scale renovation strategies in the Netherlands. In order to analyse how this works on a large scale, the renovation process of an individual house had to be analysed first. This theory resulted in a set of parameters which have an influence on the energy performance and decision process for determining an optimal large-scale renovation strategy. These parameters were integrated into the various tools and models. However, not all the parameters could be integrated into the tools and models. First of all, due to the limited timespan, not everything could be processed into the model framework. Secondly, the tools and models have to use data that is accessible and open source in order for the model framework to be usable on the entire housing stock in a fast and repeatable manner. This can be seen as the selection criteria. Only parameters related to building characteristics were used, with the exception of the statistical model. The statistical model used various parameters related to household characteristics in order to get a more reliable prediction of the energy performance. By testing the designed tools and models on a case the reliability and usability of the tools and models could be analysed.

2.2 Research questions

The main research question is:

How can the large-scale renovation strategy of existing houses be optimized by predicting the energy performance and proposing renovation strategies by using a model in particularly in the Netherlands?

In order to answer this question, multiple sub-questions had to be answered, these are outlined below.

1. **Which parameters determine the energy performance of individual houses on a district level?**
   1.1 What role does the type of housing play in the energy performance?

2. **Which parameters determine an optimal large-scale energy performance renovation strategy for individual houses on a district level?**
   2.1 What large-scale renovation strategies are used for existing houses on a district level?

3. **How can the energy performance parameters and renovation strategies be implemented into a model framework to determine the optimal renovation strategy?**
   3.1 Which parameters can be used to determine the energy performance and optimal large-scale renovation strategy for individual houses on a district level, based on accessible open databases?

4. **What improvement does the test case provide regarding the designed model?**
   4.1 What is the accuracy of the model?

2.3 Defining key concepts

Below the key concepts in this research are defined.

Large-scale renovation strategy: a long-term renovation strategy for improving the energy performance of multiple houses in an entire residential neighbourhood/district. This requires a collective renovation approach, engaging the various relevant stakeholders and using a combination of passive and active measures.

Energy performance: the total energy demand of a building, based on aa normal use of the building, including energy used for heating, cooling, ventilation, hot water supply and lighting related to the standardized energy demand of buildings according to the current state of the art.

Existing houses: residential buildings, including renovated and newly constructed dwellings, in the Netherlands.

Districts: Part of a municipality in which residential uses dominates, or from a building point of view or socio-economic structure, is homogeneously delineated as a residential area.

Model framework: The model framework is the basic structure of the proposed model. This framework is based on the combination of multiple tools and models.

2.4 Research strategy and method

In this paragraph the used research strategy and methods are described. The research strategy was based on a combination of desk research, various brainstorm sessions with experts in the renovation/building sector, an interview and a case study. The internal and external experts which were consulted in this research are listed in Appendix I. The following boundaries were set for this research:

- the research focused on the renovation of the existing building stock, that is; existing houses that have been built, not to be constructed houses;
- the proposed model framework mainly focusses on the building related characteristic of the existing housing stock, not household and socio-economic characteristics such as the type of ownership and occupant's behaviour.
- the renovation measures implemented in the proposed model framework will focus on passive measures, not active measures such as solar panels, heat pumps, lighting and ventilation.

For each sub-question, the method used to access and analyse data is described in the table below. An explanation is given regarding how data was gathered and validated. In addition, the specific results of each sub-question are given and how this related to the other sub-questions.

Sub-question	Sources and accessing data	Method	Results
1. Which parameters determine the energy performance of individual houses on a district level?	- content analysis of reports and guides established by the European Energy Performance of Buildings Directive and Netherlands Enterpise Agency regarding the calculation of the energy performance; - content analysis of academic literature on the modelling techniques used to determine the energy performances of houses on the district level.	- qualitative content analysis of guides, reports and other literature regarding what criteria determines the energy performance.	- insight into the methods and parameters used to determine the energy performance of individual houses on a single household and district level; - insight into the modelling techniques used to determine the energy performance of houses on a large-scale (district level).
1.1. What role does the type of housing play in the energy performance?	- the current state of the art academic literature on the relation between building characteristics and the energy performance	- qualitative content analysis of guides, reports and other literature regarding what the relation is between housing types and the energy performance.	- insight into the role of the type of housing with regard to the energy performance

Table 2.1 Research method sub-question 1

Sub-question 1 resulted in a set of parameters which determine the energy performance of individual houses on a single- and district level. In addition, the various modelling techniques used in literature to determine the energy performance of existing houses on a large-scale were summarized. The results from this sub-question functioned as input for the proposed model framework (sub-question 3).

Sub-question	Sources and accessing data	Method	Results
2. Which parameters determine an optimal large-scale energy performance renovation strategy for individual houses on a district level?	- content analysis of documents from large-scale renovation projects organized by housing corporations, municipalities and other governmental bodies; - content analysis of the academic literature on renovation strategies applied to houses on an individual level and large-scale. - brainstorm sessions with multiple experts from Witteveen+Bos, ERA Contour and the Efficiator[2];	- qualitative analysis of the parameters related to building-, household- and socio-economic characteristics of the existing housing stock and to what extent they influence the decision-making process for stakeholders such as housing corporations or municipalities.	- description of the various parameters which influence the decision-making process for stakeholders such as housing corporations or municipalities for determining an optimal large-scale renovation strategy.

[2] The consulted experts are listed in Appendix I. Witteveen+Bos, ERA Contour and the Efficiator are organizations active in the building sector and renovation projects. Witteveen+Bos is an engineering company; ERA Contour is a constructor and the Efficiator is a start-up company.

	- interview with S. Hartwig from the Efficiator.		
2.1 What large-scale renovation strategies are used for existing houses on a district level?	- content analysis of documents from large-scale renovation projects organized by housing corporations, municipalities and other governmental bodies.	- qualitative analysis of the renovation strategies and measurements used in these reference projects.	- a dataset of the applied renovation strategies and measures used in literature and reference projects.

Table 2.2 Research method sub-question 2

Sub-question 2 resulted in an overview of the various parameters which are relevant for the renovation process of the existing housing stock, both for single houses or multiple houses on a large-scale. Furthermore, answering this sub-question resulted in a set of large-scale renovation strategies which are widely used in renovation projects. These strategies were analysed in sub question 3 regarding the effectiveness and efficiency to be added as input for the model.

Sub-question	Sources and accessing data	Method	Results
3. How can the energy performance parameters and renovation strategies be implemented in a model to determine the optimal renovation strategy?	- results sub-questions 1 and 2 - brainstorm sessions with experts from Witteveen+Bos, ERA Contour and the Efficiator.	- based on the results from sub-questions 1 and 2 and by organizing (multiple) brainstorm sessions with experts from Witteveen+Bos, ERA Contour and the Efficiator a model framework was developed.	- a concept model framework that can reproduce the energy performance of districts and propose renovation measurements
3.1. Which parameters can be used to determine the energy performance and optimal large-scale renovation strategy for individual houses on a district level, based on accessible open data bases?	- results sub-questions 1 and 2; - data from the Central Bureau of Statistics, energy/network operators and Basis registration Addresses and Buildings (BAG)	- based on the results from sub-questions 1 and 2 and widely available datasets of parameters related to the building characteristics a selection was made of the parameters integrated into the concept model framework	- a set of parameters related to the building-characteristic of the existing housing stock used in the concept model framework

Table 2.3 Research method sub-question 3

Sub-question 3 resulted in the first concept of the model framework. This is the structure of the model, which is based on the combination of various developed tools and models. The parameters related to the building characteristics were processed into two tools and two models. This was done based on desk research regarding the applied modelling techniques in various brainstorm sessions with experts from Witteveen+Bos, ERA Contour and the Eficiator.

Sub-question	Sources and accessing data	Method	Results
4. What improvement does the test case provide regarding the designed model?	- results case study	- Based on the results the reliability and functionality of the proposed tools and models were evaluated on how they can be improved.	- an advice in the way in which the model can be improved - insight into how the model can be used to optimize the large-scale renovation strategy
4.1 What is the accuracy of the model?	- results test case - content analysis of documents and literature case study	- qualitative and quantitative analysis of the results to verify the model with the actual energy performance of the test case	- insight into the functioning and accuracy of the model

Table 2.4 Research method sub-question 4

The proposed model framework consists of a combination of various tools and models. These tools and models were tested on a case. This case was selected based upon the availability of open data regarding aspects such as actual energy performance of houses on a district level. The importance of this sub-question was to analyse how the tools and models work in practice.

2.5 Ethics

Since the research involved humans (face to face interview and brainstorm sessions with experts), ethical considerations were relevant for data gathering. One interview and six brainstorm sessions were held. This research was conducted with full compliance of research ethics norms, and more specifically the codes of conducts of the University of Twente. When carrying out the research, the ethical standards were observed and during the data gathering the highest integrity was maintained at all times. The interviewee was informed of the nature and purpose of the interview, the purpose of the research and how the data from the interview was used and dispersed. Furthermore, a consent form was used for the interview.

3 ENERGY PERFORMANCE PARAMETERS

In this chapter insight is given into energy performance parameters. To understand how the energy performance of houses can be determined on a district level, the concept of energy performance for a single house needs to be analysed first. In paragraph 3.1 an explanation is given regarding how the energy performance is defined and what methods are used to do this. In addition, the relation between the various housing types present in the Netherlands and the energy performance is investigated. Secondly, a description is given how the energy performance of houses can be estimated at a district and city scale (§3.2). At the end of the chapter an answer is given to the following sub-question:

- *Which parameters determine the energy performance of individual houses on a district level?*

3.1 Determining the energy performance on an individual building level

The energy performance is a widely used term which is often referred to as the calculated amount of energy needed to meet the energy demand related to a normal use of a building. In order to know how the energy performance can be determined for existing houses on a large-scale (e.g. district level), insight is needed in the methods used to determine this on the individual building level. Various methods are used to calculate the energy performance considering individual buildings, each with different purposes. In this paragraph these various methods are explained. The following methods are elaborated:

1. Energy performance according to the Energy Label;
2. Energy performance according to the EI;
3. Energy performance according to the EPC/BENG.

The three methods (EPC, Energy label and EI) may look similar but they distinct themselves according to the target group, function and calculation method used. In the table below, this is shown. In the following paragraphs these methods are elaborated.

Instrument	Target group	Function	Method
Energy label	To be built and existing houses	A simple representation of the energy performance (Awareness tool)	A simple calculation based on 10 characteristics
EI	Existing houses	Detailed representation of the energy performance	Detailed calculation based on 150 characteristics for one house
EPC	To be built houses	Detailed representation of the energy performance	Detailed calculation for more than one house or apartment

Table 3.1 Difference energy performance methods

These methods are based on the European Energy Performance of Buildings Directive (EPBD). In paragraph 3.1.1, a short description is given of this directive.

3.1.1 Energy performance according to the EPBD

In 2002, the European Energy Performance of Buildings Directive (EPBD) was implemented to stimulate the reduction of the energy consumption among the building sector. Through the EPBD it became mandatory for buildings to have an energy performance certificate at the point of sale or rent. Furthermore, regulatory demands on existing buildings were established (Murpy, 2016).

The Dutch legislation and regulations on the energy performance of buildings are based on the European Energy Performance of Buildings Directive (EPBD) (Publicatieblad van de Europese Unie, 2010). The general requirements of the EPBD for residential buildings included the development of a system of energy certification for new and existing buildings, regular inspections of heating and air-conditioning systems and the introduction of minimum energy performance standards for new and extensively renovated existing buildings with a useable floor area of over 1000 m2. All European member states had implemented the directive by the end of 2009, some more effectively than others (Andaloro etal.,2012).(D. Majcen, L. C. M. Itard, & H. Visscher, 2013). In 2010 the directive was revitalized. A new definition was given for the energy performance of buildings, it stated:

"energy performance of a building' means the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting" (Publicatieblad van de Europese Unie, 2010).

The methodology for calculating the energy performance of buildings is not defined in the directive and is the responsibility of individual member states. This methodology has to be in accordance with the general framework set out in the directive according to article 3 of the directive. In Appendix II this framework is shown.

3.1.2 Energy performance according to the Energy Label

In the past, a certified Energy Performance Coefficient (EPC) calculation for new buildings was sufficient to demonstrate that a building meets the energy performance requirements. Today, a valid energy label must be handed over to the buyer or tenant upon completion of the building. For housing construction an energy label for homes is required and for utility buildings an energy label for utility buildings. The energy label indicates whether the home consumes much or little energy (the energy performance). The energy label also states which energy-saving measures are possible in the home, e.g. double glazing or insulation of the roof. (Rijksdienst voor Ondernemend Nederland, n.d.[6]). The energy label for homes is an instrument that contributes to the achievement of the objectives laid down in the Energy Agreement. Energy labels are valid for 10 years (Rijksdienst voor Ondernemend Nederland, n.d.[7]). The energy label is determined on the basis of a model. This considers the most important architectural and technical data of a house. For this, the calculation model uses 10 characteristics, such as:

- construction year of the house;
- floor insulation;
- house type;
- type of heating;
- type of glass;
- solar panels and solar water heater (Rijksdienst voor Ondernemend Nederland, n.d.[7]).

Any home sold, delivered or re-rented in the Netherlands must be in possession of an energy label, according to the implementation of the European directive the Energy Performance of Buildings Directive (EPBD). There are a few exceptions[3] (Nederland, n.d.). The energy label represents the energy performance, indicated in the form of a letter G (lowest performance, bad label, low class) to A (highest performance, good label, high class). A house with a good label is therefore relatively energy-efficient. The energy performance of an existing building can be calculated based on the method as described in Appendix II (Gaalen & Staal-Guijt, 2014a)

3.1.3 Energy performance according to the EI

The energy performance of existing buildings can be calculated using the Energy-Index, or EI as well. The EI is a number which indicates the energy consumption on the basis of the amount of energy deemed necessary for the different needs related to a standardized energy use of a building (Regeling energieprestatie gebouwen, 2018).

[3] The energy label is not mandatory for monuments, (student) rooms, caravans and mobile homes smaller than 50 m2 (Nederland, 2017)

The index is mainly meant for landlords of houses below the rental liberalization limit[4]. The Energy Index partly determines the number of rental points[5] for a house. The EI is a figure with which the rent can be determined on the basis of the Housing Valuation System (Rijksoverheid, 2018; Rijksoverheid, n.d.[4]). Unlike the simple method used for the energy label, the EI uses an extensive method. The EI can only be calculated by a certified energy consultant who analyses 150 different parameters of a house. In practice, this means that the energy consultant measures the dimensions of the house in detail, notes the insulation quality and identifies the installations that are present. Based on this extensive recording, he then calculates the EI. The energy performance of a building is then expressed by a number, ranging from ≤1.20 (extremely good performance) to >2.70 (extremely bad performance) (Rijksoverheid, n.d.[8]).

3.1.4 Energy performance according to the EPC and BENG standards

Energy Performance Coefficient (EPC)

The measure for energy efficiency is called Energy Performance Coefficient (EPC). The EPC lists an energy rating for a building on an A–G scale. This standard applies to new construction of residential and non-residential buildings. The EPC fully assesses the energy efficiency of a home / residential building or utility building. This is done on the basis of building characteristics, installations and standard user behaviour. Each year the EPC values of buildings are tightened. This process led to more energy-efficient buildings by applying better energetic measures and techniques. The lower the EPC value, the better the energy performance of the building (Rijksdienst voor Ondernemend Nederland, n.d.[1]). These requirements will be replaced by the introduction of the requirements for almost net-zero-energy buildings (in Dutch Bijna Energie Neutraal Gebouw, or BENG) on the 1st of January, 2020[6] (Rijksdienst voor Ondernemend Nederland, n.d.[2]).

Bijna Energie Neutraal Gebouw (BENG)

For all new buildings, both residential and non-residential construction, the buildings must comply with the requirements for net-zero-energy buildings (BENG) starting from 2020. BENG is the result of the Energy Agreement for sustainable growth and the European directive EPBD. Unlike the method used for the EPC (one value for the energy performance), the energy performance for BENG is based on three values:

- the maximum energy requirement in kWh/per m2/per year;
- the maximum primary fossil energy use, also in kWh/per m2/per year;
- the minimum share of renewable energy in percentages (Rijksdienst voor Ondernemend Nederland, n.d.[5]).

The energy requirement is the amount of energy needed to reduce the energy losses to compensate for transmission and ventilation, with the aim of achieving a comfortable indoor climate. This is determined under standard conditions. Parameters such as the user surface, cooling demand and heat demand (Rijksdienst voor Ondernemend Nederland, n.d.[5]). The total use of primary fossil energy is calculated by deducting the generated renewable energy from the total energy usage. To determine the share of renewable energy first the absolute amount of renewable energy is calculated. This amount of renewable energy includes, in addition to the yield of PV panels, the energy production of heat pumps, solar boilers, biomass boilers etc., minus the energy consumption of the device (Rijksdienst voor Ondernemend Nederland, 2017a). Like the EPC, these values will be tightened every year. No fixed method for BENG has been established yet. At the moment, the BENG indicators can only be determined from the interim results of the calculation of the EPC (Rijksdienst voor Ondernemend Nederland, n.d.[5]).

3.1.5 Differences in energy consumption predictions and actual energy consumption

In many energy performance calculations, standardized values are used, as shown in Appendix II. These standardized values, such as a constant occupancy and constant indoor temperature, are used to ensure comparability between energy performance indicators (e.g. energy label). However, these values can differ in reality.

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[4] The rental liberalization limit determines if a house belongs to social housing, or private housing. In 2018 this limit was €710,68 (Rijksoverheid, 2018).

[5] The rental point system determines the maximum rental price of a social rental house (Rijksoverheid, n.d.[4]).

[6] For governmental buildings, these new requirements are applicable starting from January 1st, 2019 (Rijksdienst voor Ondernemend Nederland, n.d.[11])

Due to these standardized parameters, the calculated energy consumption can turn out to be very different, compared to the actual energy consumption. Since energy performance is directly related to the energy consumption, as shown in the equations in Appendix II, the calculated energy performance of a house may be unrealistic as well. This difference between the calculated and actual energy consumption is referred to as the 'performance gap' (Majcen, 2016).

This performance gap was studied by Daša Majcen. In this study, the causes of the discrepancies between the calculated or 'theoretical consumption' and the actual energy use were analyzed in the Netherlands. As shown in figure 3.1, the theoretical gas consumption can be overpredicted up to 200% in the Netherlands (Majcen, 2016).

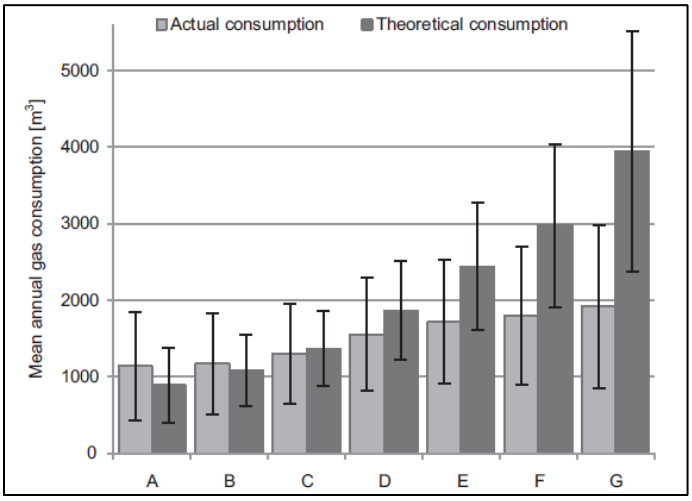


Figure 3.1 Actual and theoretical gas consumption per energy label (D. Majcen, L. Itard, & H. Visscher, 2013)

On average, the calculated energy consumption is comparable with the actual energy consumption of houses. However, when looking at a detailed level, it can be noted that the actual gas consumption is much lower compared to the theoretical consumption. The opposite can be observed for the electricity consumption, which is actually higher than calculated (D. Majcen et al., 2013). This difference can be recognized as well when comparing the energy label classes. As shown in the figure above, the theoretical energy consumption for poor labels (C, D, E, F and G) is overpredicted. On average, houses with a poor label class consume 30% less energy than calculated. For houses with a rather good label (A and B), the theoretical energy consumption is underpredicted with approximately the same amount. The total theoretical energy consumption is calculated rather well since the two effects counteract to each other, compensating for the under- and overpredictions (Majcen, 2016; Majcen, Itard, & Visscher, 2015).

Nonetheless, the performance gap results in misleading energy consumption and performance predictions, which can lead to inaccurate policy reduction targets. Furthermore, it sends an incorrect signal to stakeholders such as local governments, homeowners, housing corporations and the building industry. This performance gap is also analysed in other countries. A study in Norway indicated that the total theoretical energy consumption cannot be predicted more accurately than 35-40% compared to actual energy consumption data. This corresponds with the study by Majcen and other studies such as the research done by Sunikka-Blank and Galvin in 2012. In this research the performance gap was analysed in Germany. The study indicated that the actual energy consumption of households can be 30% lower than estimated (Sunikka-Blank & Galvin, 2012). The discrepancy in energy consumption in the Netherlands can be explained by aspects:

1. dwelling characteristics;
2. household characteristics;
3. occupant behaviour (Majcen, 2016).

In the figure below the effects of the different aspects is shown in relation to the gas consumption. In the following sections these aspects are elaborated.

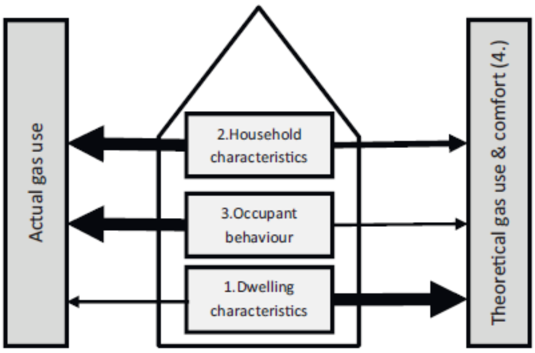


Figure 3.2 Actual and theoretical gas consumption per energy label (D. Majcen, L. Itard, & H. Visscher, 2013)

Dwelling characteristics

The dwelling characteristics relate to parameters such as the type of housing, building age, heating type and surface area. These parameters have a strong influence on the theoretical energy consumption due to the to the assumptions made in the calculation methods. Assumptions like the standard heat gains and losses, standard heated surface area and efficiencies of boilers (Majcen, 2016). As shown by the calculation methods in Appendix II, the theoretical energy consumption of a house depends on the energy use for space heating, hot water usage, auxiliary electricity consumption and lighting. The energy usage for space heating is determined by the heat gains and losses of a house. To what extent heat is gained or lost depends on the technical and architectural characteristics of the house. Characteristics such as the thermal quality of the building, the building type used, floor area, type of heating installation and ventilation type (Guerra Santin, Itard, & Visscher, 2009). The type of housing, in combination with the building age is a good indicator of the energy usage. In general, the thermal quality of older buildings is often poor. This can be explained by the rather weak building regulations in the early- and mid-20th century (more on these regulations in §4.3.). When looking at the type of housing it can be noted that the energy consumption is different per archetype[7].

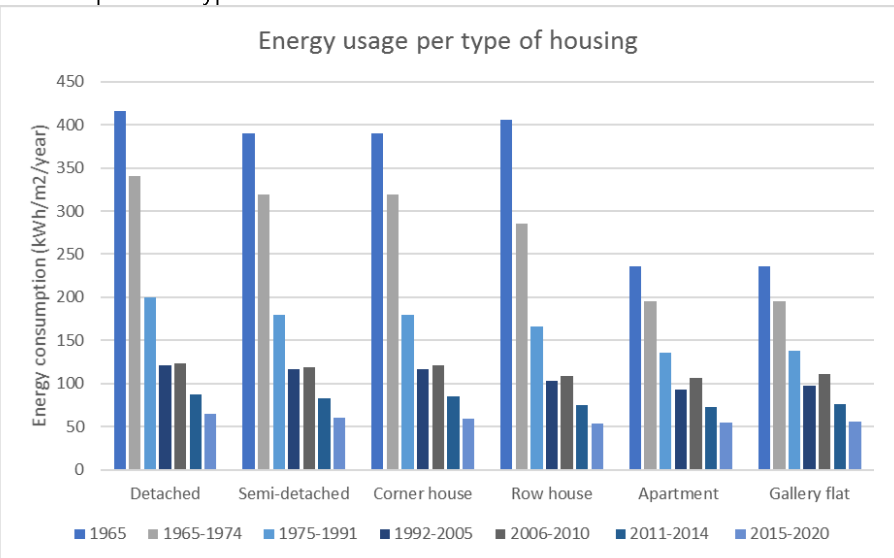


Figure 3.3 Energy consumption per archetype (Agentschap NL, 2011b)

As shown in the figure above, the energy consumption differs per archetype. This can be explained by the technical characteristics of the building, such as the geometry (building size and shape) and surface area. These characteristics determine the heat distribution, losses and gains in a building. A larger building results in a larger total surface of the building, and thus a larger transmission loss surface. The transmission loss surface is different for the various types of houses.

[7] The archetype refers to the prototypical design in which houses can be distinguished (Agentschap NL, 2011a).

For instance, a detached house has more surfaces, exposed to the outside environment, compared to a row house or an apartment. Therefore, detached houses have more heat losses than other types, resulting in a higher heating demand. Another aspect which explains the difference is the construction period (related to the constructive principles and materials). The construction period reflects the building practice and required energy performance of houses used in that period (Ballarini, Corgnati, & Corrado, 2014).

Household characteristics

Household characteristics are related to parameters such as the age of the occupant, number of occupants, household income and occupant behaviour. These parameters have a large effect on the actual energy consumption. According to numerous studies, age is a key characteristic which can be related to the energy consumption. Studies show that households with relatively older occupants tend to consume more energy than younger households. Older occupants tend to consume more energy required for space heating, due to the higher comfort standard with regard to the temperature setting (Liao & Chang, 2002; Linden et al., 2006). The number of occupants is a relevant parameter as well. Larger households tend to have bigger houses, as well as a higher hot tap water demand. The average income of a household is another decisive parameter regarding the energy consumption. Households with a relatively high income tend to consume more energy than households with a low income. In general, people with a higher income tend to have more electrical applications, tend to keep a warmer indoor temperature and have larger houses in overall (Guerra Santin, 2010). Poorer households on the other hand, use less energy since they have less money to spend on energy bills. Furthermore, these households often live in poorly insulated houses (Majcen, 2016).

Occupant behaviour

This aspect has to do with the energy behaviour of the household, such as the number of days present in the dwelling, temperature preferences, ventilation preferences, showers per week and average temperature during the day. The calculations shown in the previous paragraph either standardise or ignored these parameters. This can explain the difference in actual and calculated energy consumption and performance. The problem is that the effects of the occupant's behaviour are complex and are associated with the building characteristics (Guerra Santin, 2010). For instance, people use higher temperature settings in houses which have good insulation, something which can be explained by the ´rebound effect´ (this is explained later on). Other factors such as the type of thermostat (manual or programmable) affect the behaviour as well. Households with a programmable thermostat use less energy than households with a manual thermostat. In the first case, occupants have direct feedback on the temperature setting (Guerra Santin, 2010).

As stated before, occupants tend to increase their comfort demands when the energy performance increases, which in the literature is referred to as the 'rebound effect'. The rebound effect means that the energy consumption increases, even though energy saving measures are implemented. This is caused by the increased comfort settings of the occupant, after applied measures. People unconsciously compensate for the energy savings: for instance, turning on the lights for a longer period after installing LED lights. This mechanism can explain the underpredictions of the energy consumption and performance in well-performing houses in the Netherlands (Majcen, 2016). The opposite effect can be observed as well. In contrary to the rebound effect, the 'pre-bound effect' explain the overpredictions of the energy consumption in houses with a poor energy performance. In general, poor households pay more attention to reducing the energy consumption in poor performing houses to save money. These households focus more on keeping a low indoor temperature, heat less rooms and use less hot tap water (Majcen, 2016; Sunikka-Blank & Galvin, 2012).

The rebound and pre-bound effects are one of the causes of the over- and underprediction of calculated energy consumption, performance and reductions. These effects can limit the actual energy savings due to renovation measures. Studies show that the rebound and pre-bound effect can influence up to 30% of the actually saved energy through renovation measures (Majcen, 2016). Figure 5 shows the relation of the rebound and pre-bound effects and the actual energy savings. Both effects result in lower actual saved energy than calculated, causing an unrealistic image of the effects of renovation measures.

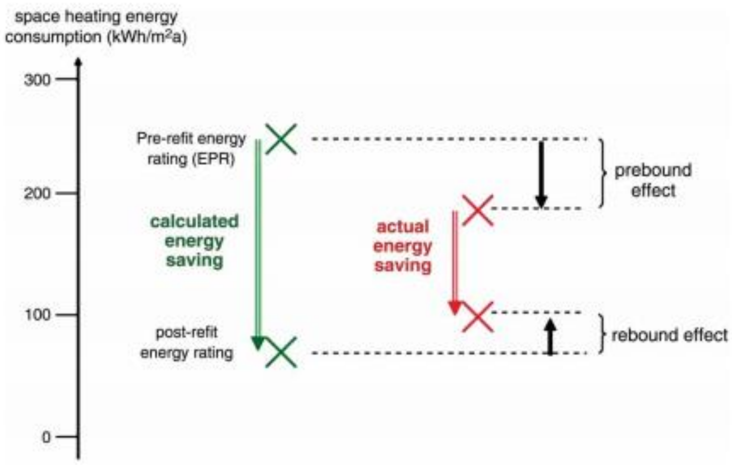


Figure 3.4 The relation with the rebound and pre-bound effects and energy savings (Sunikka-Blank & Galvin, 2012)

3.2 Energy performance parameters on a district and city scale

In order to determine the energy performance on a larger scale, such as the district level, the energy usage of an individual building cannot be simply multiplied by the number of buildings in a district. As seen in the figure below, the energy demand of a district can vary, even when the buildings are from the same building type and characteristics. In order to combine groups of buildings while maintaining a reliable representation of energy interactions at the district or city level various parameters have to be accounted for. For instance, if a house, or group of houses is connected to a heat or gas network, or uses a biomass or electrical boiler (Fonseca, et. al, 2015; Monzón, et. al, 2018).

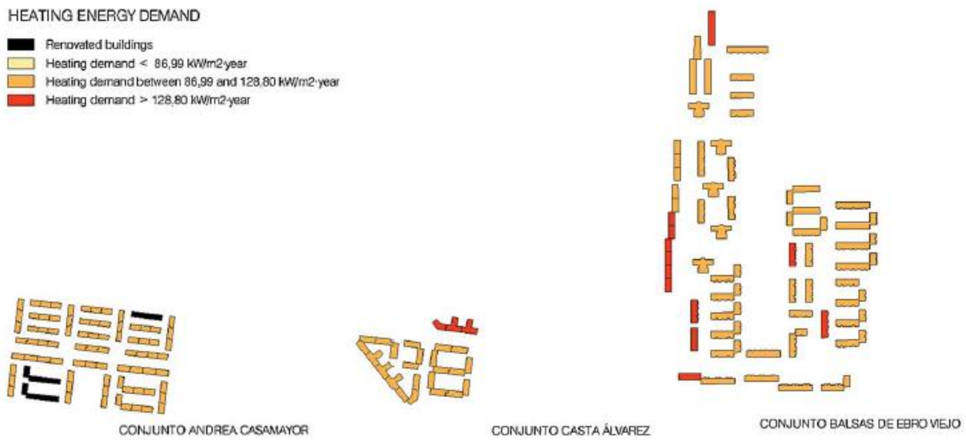


Figure 3.5 Differences in heating demand per housing block (Monzón, et. al, 2018)

As stated in chapter 1, major efforts are needed to realize an energy- and CO_2 neutral building stock by 2050. These efforts include means to analyse the energy performance of buildings, and by doing so, determining potential renovation strategies. By creating a systematic approach which can be used at any location that addresses existing houses at a district or city scale, stakeholders such as policy makers or housing corporations can identify an optimal renovation strategy for existing houses (Tardioli, Kerrigan, Oates, O'Donnell, & Finn, 2015). In this paragraph a description is given regarding the various methods and models used to analyse the energy performance of existing houses on a district level. First of all, the modelling techniques are described. Then, numerous examples are given how these techniques and which parameters are used in practice.

Large-scale modelling techniques of the energy performance

Various studies regarding decision support models and tools have been performed to assess the energy performance of buildings and districts. When it comes to these models Swan, et. al. recognized two techniques to model energy consumption or performance: top-down and bottom-up (figure 3.6).

In the following paragraphs various top-down and bottom-up approaches are elaborated. Insight is given into the parameters which are used to determine the energy performance of houses on a district and city scale. In addition, the advantages and disadvantages of the two approaches are discussed.

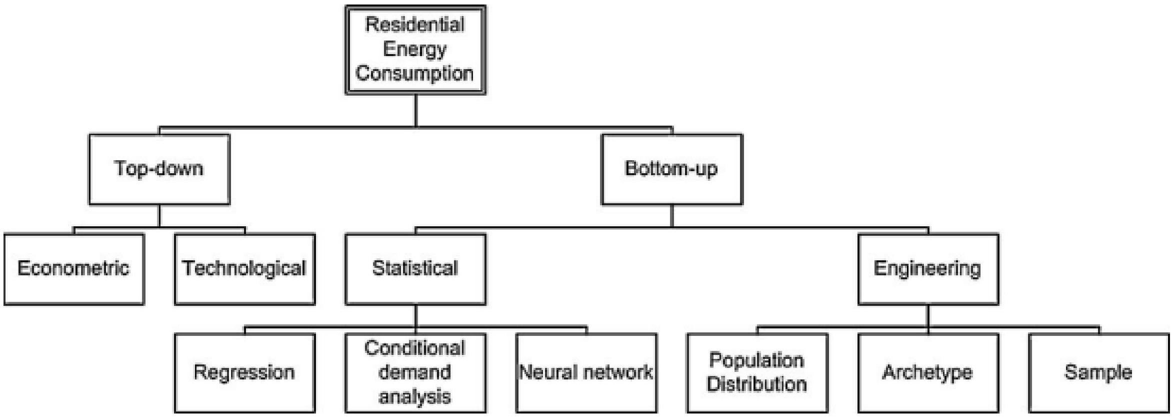


Figure 3.6 Top-down and bottom-up techniques for determining energy consumption (Swan, et. al, 2009)

3.2.2 Top-down models

Top-down models predict the energy consumption or performance of existing houses at an aggregated level. These models are founded on the correlation between energy consumption and economic variables such as gross domestic product, income and unemployment. These values are then connected with econometric or technological indicators of the existing housing stock on a regional or national level (Kavgic et al., 2010).

Top-down models are mainly used to analyse certain trends and long-term changes in the national building sector regarding energy consumption or performance. They can provide predictions or estimates in order to assess certain measures. For instance, improving the energy performance of a certain building type on a national scale (Kazas, Fabrizio, & Perino, 2017; Reinhart & Cerezo Davila, 2016). However, top-down models do have some disadvantages compared to bottom-up models. First of all, a huge amount of data is needed since it mainly focusses on macro-level, e.g. entire building stock. Second of all, the models cannot be used to analyse individual buildings on a large scale. Specific characteristics of individual buildings, technologies or measures are not considered (Elci, Manrique Delgado, Henning, Henze, & Herkel, 2018). Therefore, it is limited to the general characteristics of the total building stock, which makes it difficult to predict the energy performance on a detailed level.

In short, top-down models analyse the existing housing stock as one entity. Based on the aggregated characteristics of the housings stock, the energy demand or performance is modelled. Top-down models extrapolate from aggregated data on the macro-economic level and therefore, are not capable to analyse the energy consumption or performance of individual houses on a district level. This makes top-down models less suitable for the purpose if this study, which is to analyse individual houses on a large-scale, e.g. district or city level. Bottom-up models, on the other hand, are able to scale down in order to model individual houses on a large-scale (Frayssinet et al., 2018). According to Kazas et al and Reinhart & Cerezo Davila, bottom-up models are expected to become a crucial decision support tool for stakeholders such as municipalities, urban planners and policy makers (Kazas et al., 2017; Reinhart & Cerezo Davila, 2016).

3.2.3 Bottom-up models

Bottom-up models are used to analyse the building stock on a meso- or micro level, e.g. predicting the energy consumption of individual houses. These models can offer more insight into the characteristics of the building stock and enable the assessment of measures at individual houses on a large-scale (Elci et al., 2018). The energy performance can be analysed by starting at a disaggregated level, such as separate building characteristics. By using numerous statistical methods, data can be aggregated to represent the entire building stock. This can be performed in a district, urban or national scale. A bottom-up approach can use both types of data, aggregated and disaggregated, unlike top-down approaches (Kazas et al., 2017). Parameters such as construction period, surface area, building type and level of education can be used in bottom-up models.

This data can be calibrated or benchmarked with available measured data such as gas consumption. This is especially important when analysing large numbers of buildings to assess the difference between the predicted and measured data (Boehme, Berger, & Massier, 2015). Usually, the predictions will be more accurate if more parameters are used, that is when the parameters used to correlate with aspects such as the energy consumption or performance. However, this does require more data (Boehme et al., 2015).

In general, two different types of bottom-up models can be found in literature: statistical and engineering-based models. Engineering based models use specific quantitative data regarding characteristics of existing building to model the energy consumption or performance. The advantage of using engineering-based models is the capability of predicting the potential energy savings of buildings due to the implementation of renovation measures. However, these models are very complex, are limited to specific data of a certain district and require high-levelled data input (Mastrucci, Baume, Stazi, & Leopold, 2014). Statistically based models are rather simple compared to engineering approaches. In general, statistical models aim at analysing the correlation between end-use energy consumption of single buildings and a set of parameters. These parameters are related to occupant's behaviour or building- and household-characteristics such as surface area, income and building type. The advantage of statistical models is the ability to consider the behaviour of occupants. Therefore, statistical models can offer reliable information about the energy characteristics of buildings. However, these approaches are not able to consider the impact of renovation measures (Mastrucci et al., 2014).

The key advantage of bottom-up models is the capability to predict the energy consumption or performance at a detailed level (individual buildings) on a large-scale, e.g. neighbourhood, district and even city and national level. Various bottom-up models have been developed in the past decades. A couple of these relevant models and tools are described in the following sections.

Data-driven energy usage predictive model on city-scale

Constantine E. Kontokosta and Christopher Tull from the United States designed a bottom-up model which can be used for policy makers to predict the energy use at the building, district, and city level. The model uses actual energy usage data of more than 23.000 buildings, land use data, energy disclosure policies and predictors from property and zoning information. With the use of statistical models, the energy usage of 1.1 million buildings in New York City could be generated (figure 3.7). Building specific parameters such as building size, age, use, occupancy characteristics and construction type were utilized with the use of a regression model. By validating the output at the building level using zip code actual energy consumption and building data the accuracy could be assessed. The output of the model creates the ability for policy makers to evaluate the impact of policy alternatives to advance energy use reductions. This city level model enables to target regulations and incentives by clustering building types based on intensive energy users. For instance, incentives for renovations or building inspections and enforcement (Kontokosta, et. al, 2017).

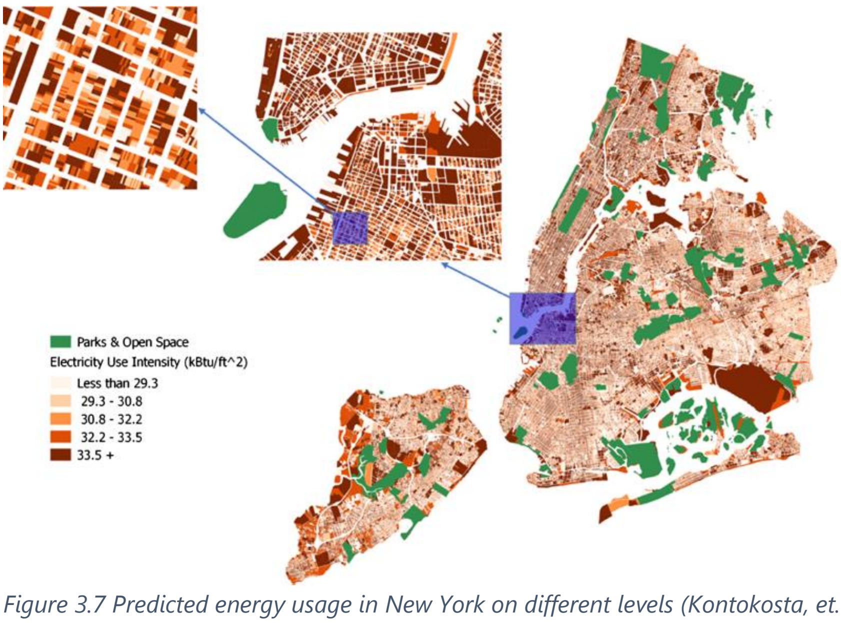


Figure 3.7 Predicted energy usage in New York on different levels (Kontokosta, et. al, 2017).

The downside however, is that the model relies heavily on local existing and actual energy use and building attribute data. Without these databases it becomes hard to predict, extrapolate and verify the energy usage. Furthermore, the model lacks information regarding renovation strategies (Kontokosta, et. al, 2017).

Building age as an indicator of energy consumption

In a study conducted by (Aksoezen et al., 2015) in Switzerland, a bottom-up statistical method was used to analyse the relation between the building age and the energy consumption. The analysis is based on a combination of a GIS- and a statistical model. By deriving specific spatial information and building characteristics from the GIS-model of the City of Basel a large database was developed. Detailed information on 20.802 buildings, in combination with the average energy consumption related to the various districts were used to analyse the whole city. The buildings were analysed based on the correlation between the energy consumption, the average building age and the compactness (the ratio of the outer surface to volume) of the buildings (Aksoezen et al., 2015). The statistical model showed that there was a strong relationship between these parameters. The research showed that buildings constructed prior to 1921 performed better than the average. This could be explained due to the rather small surface area and compactness. Buildings dating from 1947 to 1979 performed worse, compared to the average. This can be explained by the larger user surface and compactness (Aksoezen et al., 2015).

Energy atlas

Established in Sweden, the Energy Atlas is a bottom-up model which can be used to visualize and analyse the energy performance and renovation potential for multifamily houses on a district, city or municipality to the national level. The tool enables to estimate aggregated data on energy use, socio-economic challenges and costs associated with possible renovation strategies. The model aggregates information regarding the energy performance, building ownership, renovation status, and socio-economic status of inhabitants from various data sources. Various renovation scenarios are used in this model. These scenarios were based on aggregated data of annual costs required for the renovation of buildings. In addition, the atlas visualizes the energy use and renovation targets based on income level, energy classes and renovation status in 2D maps and 3D models (Johansson, Olofsson, & Mangold, 2017). The atlas can be used for policymakers to use as a support tool for defining a renovation strategy. By using a bottom-up technique target renovation area can be identified which high average energy use, low average income level and need renovation in the coming 10 years. However, the tool does not provide a detailed analysis of the energy performance or specific renovation strategies. The tool merely indicates potential energy savings and energy usage based on aggregated data (Johansson et al., 2017)

Integrated model for building energy consumption patterns in neighbourhoods and city districts

Developed in Switzerland this model integrates various existing models used in the spatial and energy planning sector. By determining the energy services of existing and future buildings in the residential, commercial and industrial sectors the consumption patterns and potential energy efficiency measures are assessed. This is done at the at the neighbourhood and city district level. Existing modules like spatial analysis, dynamic building energy modelling and energy mapping are integrated to provide a multi-scale and multi-dimensional model. Multiple parameters are considered in the model, for instance, the solar radiation on building surfaces, self-shading properties and building specific aspects like their geometry and their envelope. This enables the model to evaluate the performance of the various components of the buildings. Moreover, by clustering the information a spatial analysis can be made of the energy consumption patterns at a neighbourhood/district scale as can be seen in Appendix III. A geographical information system (GIS) framework is used as a basis for the analysis and visualization of the information. In the analysis of energy efficiency measures in buildings 3 standardized renovation packages are used: building envelope retrofit, building cooling system retrofit and upgrades of electrical appliances and lighting. Of each strategy the potential energy savings are estimated by comparing the current energy consumption with a hypothetical scenario where all buildings attain the retrofit requirements of the local building standard (Fonseca, et. al, 2015).

A GIS-based statistical bottom-up approach to estimate energy savings

This bottom-up approach uses a combination of a statistical and engineering model in order to predict the energy consumption and analyse energy savings. Using a GIS-tool specific data can be required of the housing stock of an entire city. This method was tested on a district in Rotterdam. By downscaling measured gas and electricity consumption aggregated on a post-code scale of the entire city the energy consumption was predicted, as shown in Appendix III.

With the use of a linear regression model, a correlation was found between the energy consumption and building and household characteristics. Parameters were used such as the type of housing, construction period, the floor surface and number of occupants. With this method the energy consumption of individual houses could be predicted of the entire housing stock in Rotterdam. This method offered a good prediction of the energy consumption, more than 80% of the predicted values deviated less than 20% compared to measured data. With the use of an engineering model, the potential energy reduction could be assessed. By using specific 3D data of the city of Rotterdam, the impact of generalized renovation measured was analysed. This combined bottom-up approached provided key information in order to prioritize certain renovation measures in the city of Rotterdam (Mastrucci et al., 2014; Nouvel et al., 2015).

3.3 Sub-conclusion

As shown in this chapter there are various definitions used in practice regarding "energy performance". In general, it is expressed as the total energy demand ($Qtotal$) needed for aspects such as heating, lighting, ventilation, cooling and hot water. This energy demand is then related to a standardized energy usage of a building to show how a building performs compared to present energy performance standards. On an individual building level this can be expressed via the use of an energy performance indicator such as an energy label, energy index or energy performance coefficient. When looking at the various approaches used to determine the energy performance of existing buildings on a large-scale, e.g. district level, two distinctive methods can be noted: top-down and bottom-up. Top-down models do not consider specific characteristics of individual buildings, and cannot be used to analyse the specific energy performance of individual buildings on a district or city level. Bottom-up approaches, however, are able to use specific building characteristics of individual or groups of buildings in order to calculate or predict the energy consumption and performance of individual buildings and then extrapolate this to an entire district, city or country (Frayssinet et al., 2018). In the past few years, various bottom-up models have been developed for analysing, predicting and modelling the energy demand and performance of the built environment on a large scale (§ 3.2.3.). In the presented methods and modelling techniques with regard to the energy performance of houses, various parameters are used. Most of these parameters used in bottom-up models are related to the building- and household characteristics of houses as shown in the table below.

Aspect	Parameters
Building characteristics	Year of construction
	Type of housing
	Surface area
	Building systems (ventilation and heating)
	Thermal/insulation performance
	Number of floors
	Compactness (ratio outer surface and volume)
Household characteristics	Income level
	Number of occupants
	Age of the occupants
	Consumption behaviour

Table 3.2 Parameters related to the energy performance (Aksoezen et al., 2015; Fonseca & Schlueter, 2015; Johansson et al., 2017; Kontokosta & Tull, 2017; Mastrucci et al., 2014)

In this study two bottom-up models were developed in order to predict the energy performance of individual houses on a district level. These two different approaches use various parameters related to the building characteristic which have an influence on the energy performance. This chapter provides a literature framework which is used to determine the parameters used in the models. The selection of these energy performance parameters model is carried out in chapter 5. In the following chapter the various renovation strategies used in practice are elaborated.

4 THE OPTIMAL LARGE-SCALE RENOVATION STRATEGY

The starting point of this chapter is the need to renovate the existing housing stock, in order to improve the energy performance. This is needed to reduce the energy demand and to reach the various energy goals. For instance, an energy neutral building stock by 2050. In this chapter an answer is given to the following sub-question:

- *Which parameters determine an optimal large-scale renovation strategy for individual houses on a district level?*

Based on various reference (renovation) projects, expert judgement and literature, the key parameters and large-scale renovation strategies were identified. First of all, the various definitions regarding 'renovation' are clarified. This thesis uses the term 'large-scale' renovation, which refers to the renovation of multiple houses on a neighbourhood or district(s) scale. Not to be mistaken with the term large-scale renovation 'strategy'. In practice and in the found literature, numerous definitions are used regarding the term renovation. In paragraph 4.1, these various definitions are discussed and in addition, a clear distinction is made between these used definitions. In paragraph 4.2 the renovation process of the existing housing stock is discussed. In this paragraph the various renovation measures and the large-scale renovation 'strategies' are explained. In paragraph 4.3, an elaboration is given of the decision-making process by stakeholders such as housing corporations regarding large-scale renovations. Furthermore, the parameters influencing this decision-making process are elaborated.

4.1 Definitions of renovation

In practice the term 'renovation' is often interchanged with the terms 'refurbishment' and 'retrofitting'. The definitions are often the same, however the terms can be distinguished from each other. In this paragraph the various definitions found in the literature are elaborated. Based on these definitions one term is distinguished which is used in this thesis.

In a study by (Vainio, 2011) a certain hierarchy was used to categorize the various terms. According to this study the term renovation can be defined as: "*altering a built object towards a desired state, either technologically or functionally*". Refurbishment, however, is used when a building, or parts are renewed. The term retrofit is defined as improving the quality of the built object significantly, e.g. by improving the energy efficiency (Vainio, 2011). Although this gives some distinction between the terms, they can still be interpreted as the same; altering a built object towards the desired state and improving the quality significantly are quite similar.

A more precise distinction between the terms can be found in a study by T. Konstantinou (20rij14). In this thesis the different terms are categorized based on the level of intervention, as shown in the figure below.

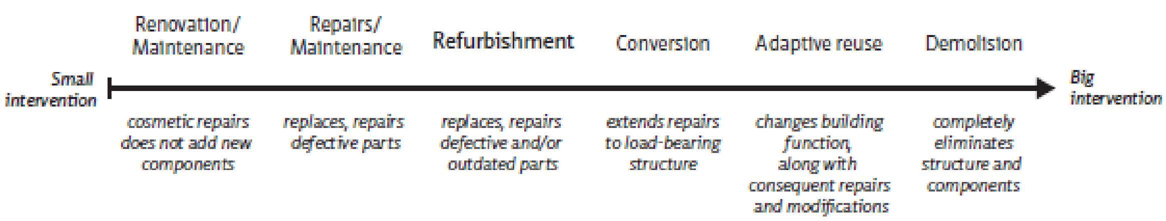


Figure 4.1 Definitions according to the level of intervention (Konstantinou, 2014)

As seen in figure 9, renovation is defined as the cosmetic repairs of building components. Refurbishment focuses on repairing or replacing defective and/or out-dated building components. Interventions such as improving the acoustic, energy performance or upgrading of fire protection are accounted for through refurbishment (Konstantinou, 2014).

In a study on the smart renovation of houses and neighbourhoods by I. Kramer (2016), renovation is defined as: "*the process of upgrading an existing building without changing its initial purpose. In this process, adjustments are made to increase the technical, economic and social lifespan of a building"* (Kramer, 2016).

In the Energy Performance Building Directive, the term 'major renovation' is used. This means the renovation of a building where:

a. the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated, or;
b. more than 25% of the surface of the building envelope undergoes renovation.

Member States may choose which definition to apply, a or b (Publicatieblad van de Europese Unie, 2010). In the Netherlands, the term major renovation is described in the Dutch Building Act (Bouwbesluit). Within the act the regulations for renovations are elaborated. The term major renovation is described as: "*more than 25% of the surface of the building envelope undergoes renovation*". When the surface is less than 25% it is seen as partially renovating or changing or enlarging a building. For both terms different energy performance standards apply (Bouwbesluit 2012; Regeling Bouwbesluit 2012, 2018).

Another term used, is 'deep renovation', or 'deep energy renovation'. This term refers to renovation strategies that use the full potential of improvements regarding the energy performance of buildings. Instead of focusing on standard renovation measures, deep renovation combines several measures into one integrated renovation strategy, applied to the building envelope and installation system (Agliardi, Cattani, & Ferrante, 2018). According to the Buildings Performance Institute Europe (BPIE), deep renovations are specified as renovations that achieve energy savings between 60-90%. These kinds of strategies require a holistic approach, considering the renovation strategy as a combination of measures cooperating together (BPIE, 2011).

In this thesis the term 'large-scale renovation' is used, not to be mistaken with the term 'large-scale renovation strategy'. Based on the definitions as described above, a large-scale renovation can be seen as improving the energy performance of multiple buildings on a large-scale, e.g. neighbourhood/district level by altering the building envelope, ventilation system and possible renewable energy production. The term large-scale renovation strategy is explained in paragraph 4.2.

4.2 Renovating the existing housing stock

Various renovation measures can be applied in order to improve the energy performance of the existing housing stock. A certain energy performance level can be realized with different sets of renovation measures. The selection of a combination of renovation measures, focused on the improvement of the building envelope and installations for the long-term, in an integrated approach is called a 'renovation strategy' (Agliardi et al., 2018). The thesis focusses on large-scale renovation strategies. A 'large-scale renovation strategy' can be seen as a long-term strategy for improving the energy performance of multiple houses on a neighbourhood/district level. However, in order to understand how large-scale renovation strategies work, insight is needed in applied renovation strategies on a single building scale. First of all, a quick overview is given of the various renovation measures which can be combined into renovation strategies (§4.2.1.). Then, the various types of renovation strategies are elaborated in paragraph 4.2.2. This paragraph focusses on the single building level. In paragraph 4.2.3 the large-scale renovation strategies are discussed with the use of example projects.

4.2.1 Renovation measures

In this sub-paragraph, a short description is given of the renovation measures which can be applied to houses. An overview of the measures was derived from the 'Façade Refurbishment Toolbox'. This toolbox, proposed by Thaleia Konstantinou, can be used for supporting the design of residential energy upgrades. In her master thesis, all the possible renovation measures, found in literature and practice, were categorized by the type of intervention and basic renovation principles (Konstantinou, 2014).

These measures can be separated into passive and active measures. Passive measures use the design and properties of the building envelope to minimise the heat losses and/or maximise the heat gains, thereby reducing the energy demand. Active measures are systems for conditioning the building such as heating systems and solar power technologies to produce and distribute the energy needed. These measures can be linked to the Trias Energetica concept. The Trias Energetica uses a hierarchical approach in order to make an energy efficient and sustainable design by:

1. reducing the energy demand;
2. using sustainable energy sources as widely as possible;
3. using fossil fuels as efficiently as possible for the remaining energy demand.

Figure 10 presents an overview of the passive and active design principles, in relation to the Trias Energetica steps (Konstantinou, 2014).

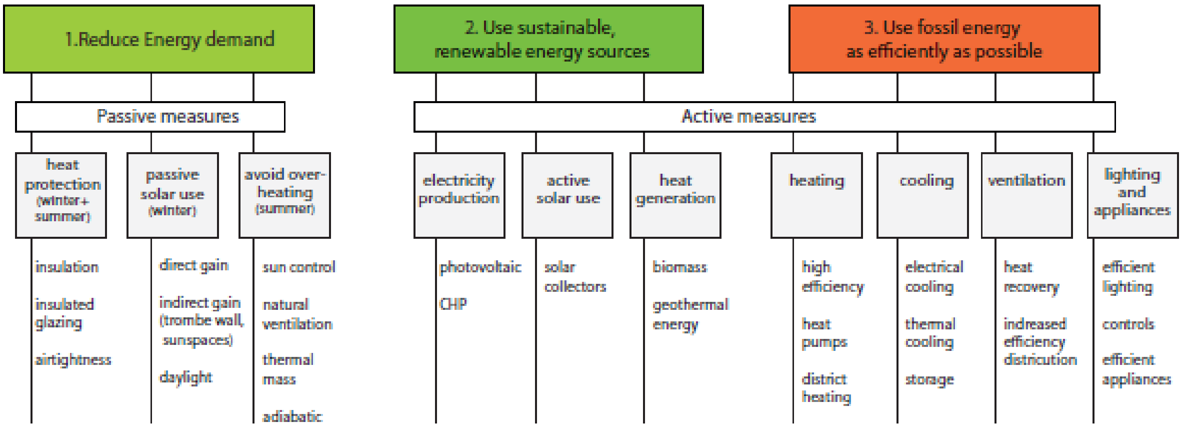


Figure 4.2 Renovation measures according to the Trias Energetica steps (Konstantinou, 2014)

The possible passive and active renovation measures are categorized according to the building component they are applied to, namely:

- external and internal walls
- windows
- floors
- roof
- building installations

In Appendix IV, these measures are elaborated in detail.

4.2.2 Renovation strategies - design principles

A renovation strategy for a house can be seen as a combination of renovation measures that are set to improve the energy performance for the long term. In this paragraph, more insight is given regarding the various renovation strategies found in the literature. The mentioned strategies in this paragraph have a focus on the single building level. Even though, the basic principle of these strategies applies as a baseline for large-scale renovation strategies, as shown in paragraph 4.2.3. Konstantinou identified several categories of renovation strategies based on the current state-of-the art with regard to used strategies, best practices and common renovation projects. These categories represent an integrated approach of the widely used renovation options. Renovation strategies can be grouped given the approach in which building components are replaced, upgraded or added and their influence on the energy performance. The various renovation strategies can be implemented in different distinctive ways, nevertheless, similar principal concepts underlie the renovation strategies (e.g. trias energetica). In figure 11 these various renovation strategies are shown. Note: since design possibilities are limitless, the possible renovation strategies are not exhaustive. The purpose of this figure is to give an overview of the general renovation strategies, regardless of the many possibilities (Balkuv, 2017; Konstantinou, 2014).

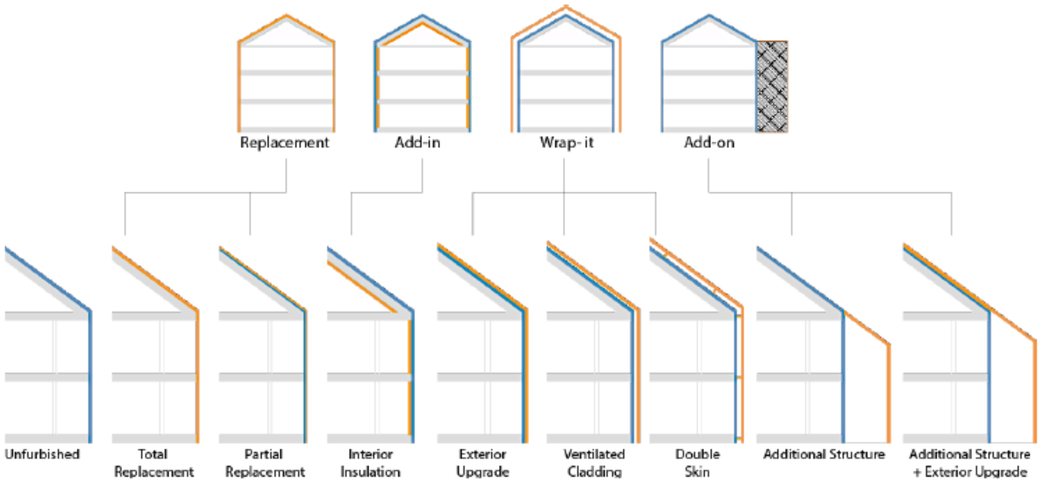


Figure 4.3 Different renovation strategies categorized by intervention type (Balkuv, 2017; Konstantinou, 2014)

Each strategy involves a different scale and has different advantages and disadvantages, as shown in Appendix XII.

4.2.3 Large-scale renovation strategies – example projects

In the previous paragraphs a brief description is given regarding the various existing renovation strategies found in the literature. These strategies focused on a single building level. In large-scale renovations these strategies can be implemented in different distinctive ways, nevertheless, the key principle of the applied strategy remains similar. In this paragraph an elaboration is made regarding to what extent these renovation strategies are applied on large-scale. With the use of various examples, the applied renovation strategies, active and passive measures used in practice are highlighted in the Netherlands. Furthermore, an elaboration is given how problems were tackled in these renovation projects, which solutions were chosen to reach a certain goal and how these solutions related to an improved energy performance. In the following sections various renovation projects are shown, realized in the past years to show the different applied renovation strategies and measures.

Energy neutral renovation Melick, Limburg
In Melick the housing association Wonen Limburg, together with VolkerWessels, supplied the first four pilot homes within the context of the Stroomversnelling. The first pilot house was completed at the beginning of 2014. The four blocks consisted of 60 houses of the same type; identical row houses built in the 60's. The housing blocks were renovated towards an energy neutral concept. The renovation strategy was based on 'wrapping' the houses in a second layer. For the houses a combination of renovation measures was used. The houses are all-electric and all new installations are brought together in an external portal. Each house got a completely new façade that insulates the house well, this is done with a sandwich construction for the façade. The heating system was replaced by an individual air to water heat pump in combination with low-temperature floor heating. A total of 21 PV panels per building were integrated into the roofs and the houses. Using this approach, the energy demand was reduced to 8,876 MJ/year and improved the energy label to A++ (Nieman Bouwfysica, 2015[1]). In the table below the details of the renovation project is shown.

Component	Before the renovation	After the renovation
Floor	No insulation	180 mm insulation (Rc value of 8,72)
Walls	60 mm thick cavity insulation	180 mm insulation (Rc value of 8,93)
Roof	No insulation	180 mm insulation (Rc value of 8,79)
Windows	Single and double glazing	Triple glazing (U value of 1,40)
Heating	VR-boiler	Air to water heat pump
Ventilation	Natural ventilation	Balanced ventilation with heat recovery
Renewable energy production	None	29,4 m2 PV panels
Energy label	Unknown	A++

Table 4.1 Applied renovation measures Melick (Nieman Bouwfysica, 2015[1])

Energy neutral renovation Siboldus street Bolsward, Friesland

The energy-neutral home improvement of the Siboldusstraat is a pilot project for housing corporation 'Elkien' to investigate whether it is possible to make a much larger energy leap for less than the national budget. The houses have undergone a metamorphosis to realize an improvement of label C to label A++. The houses consisted of the same type: row houses which were built in the 70´s. The complete outer shell has been renewed by replacing the existing building envelope with a new exterior envelope. Cavity insulation was applied in combination with innovative insulation at the floors and attic. The houses are equipped with HR ++ glass and in addition to adjustments to the exterior envelope, various items have also been adjusted in the houses such as PV panels and a heat pump. This way the gas connection has been removed (Nieman Bouwfysica, 2015[2]).

Construction	Before the renovation	After the renovation
Floor	No insulation	300 mm HR thermo chips (Rc value of 5,75)
Walls	60 mm thick cavity insulation	60 mm insulation (Rc value of 1,86)
Roof	50 mm thick insulation	135 mm insulation (Rc value of 4,27)
Windows	Single and double glazing	HR++ glazing (U value of 1,80)
Heating	HR-107 boiler	Air to water heat pump
Ventilation	Natural ventilation	Balanced ventilation with heat recovery
Renewable energy production	None	44,8 m2 PV panels 2,7 m2 solar collector
Energy label	C and D	A++

Table 4.2 Applied measures Siboldus street (Nieman Bouwfysica, 2015[2])

Passive house renovation Nieuwkuijk, Noord-Brabant

In this renovation project 16 small apartments were upgraded to the level of a passive building in 2011. Two blocks consisting of the same type, rental apartments from the 70's, owned by the housing corporation 'Stichting Woonveste' were energetically improved. For both blocks a renovating strategy was used based on covering the existing envelope with a second layer, as well as adding an additional component. After the renovation the apartments have a marginal energy requirement for space heating of up to 25 kWh/m^2. The total building envelope was insulated extremely well (Rc ≥ 8 m2K/W and insulated frames with three-layer glass), the buildings are completely airtight and extra attention has been paid to the limitation of thermal bridges. In addition, the apartments are ventilated by means of a balanced ventilation system with a high return on heat recovery and only one central radiator is required due to low transmission losses (Nieman Bouwfysica, 2015[3]).

Construction	Before the renovation	After the renovation
Floor	No insulation	230 mm HR thermo chips (Rc value of 8,07)
Walls	50 mm thick cavity insulation	230 mm insulation (Rc value of 8,94)
Roof	No insulation	230 mm insulation (Rc value of 8,26)
Windows	Single glazing	Triple glazing (U value of 0,80)
Heating	VR boiler	HR-107 boiler
Ventilation	Natural ventilation	Balanced ventilation with heat recovery
Renewable energy production	None	None
Energy label	D and E	A+

Table 4.3 Applied measures Nieuwkuijk (Nieman Bouwfysica, 2015[3])

Energy neutral renovation in Heerhugowaard

This project concerns the energy neutral renovation of 166 different types of houses in Heerhugowaard and Soesterberg. In Heerhugowaard the contractor 'BAM Woningbouw' and housing corporation 'Woonwaard' renovated 57 row houses from the 1970's to energy neutral within 10 days. In the project, various techniques were used to realize all-electric neighbourhoods. Measures are used such as prefab roofs, integrated PV panels, triple glazing and heat pumps. The façade is covered with a composite, a light material that is comparable to the material used for boats; super light and waterproof (Rijksdienst voor Ondernemend Nederland, 2015; n.d.[10]).

Construction	Before the renovation	After the renovation
Floor	No insulation	Insulation chips (Rc value of 5)
Walls	50 mm thick cavity insulation	Insulation with an Rc value of 5
Roof	No insulation	Insulation with an Rc value of 5
Windows	Double glazing	Triple glazing (U value of 0,80)
Heating	HR boiler	Air to water heat pump
Ventilation	Natural ventilation	Balanced ventilation with heat recovery
Renewable energy production	None	28 PV panels
Energy label	C	A+

Table 4.4 Applied measures Heerhugowaard (Rijksdienst voor Ondernemend Nederland, n.d.[10])

Energy neutral renovation Hof van Egmond Slachthuisbuurt, Haarlem

The Hof van Egmond complex is located in the Slachthuis neighbourhood in Haarlem and counts 154 social rental housing. The complex has a monumental status. The houses typed as so-called 'portiekwoningen', or porch houses were built in the years 1924 -1928. The renovation strategy was based on a so-called high-level monumental renovation approach by the preservation of the facades and upgrading the building from the inside. The project was divided into 11 phases and executed in 2014. The envelope was upgraded in an economically responsible manner, by stripping the houses as a whole; the monumental façades and the ground floor were post-insulated, the roof and floor were replaced by prefabricated concrete, of which the roof is insulated high quality. The windows were restored to their former state and equipped with HR ++ glazing and in addition, the existing outdated VR boiler and gas heaters were replaced by an HR-107 boiler or a geothermal heat pump. Furthermore, the flat roof is provided with PV panels. As a result, the houses were upgraded to label A++ (Niemand Bouwfysica, 2015[4]).

Construction	Before the renovation	After the renovation
Floor	No insulation	170 mm insulation (Rc value of 4,40)
Walls	No insulation	110 mm insulation (Rc value of 3,11)
Roof	No insulation	200 mm insulation (Rc value of 5,22)
Windows	Single glazing	HR++ glazing (U value of 0,80)
Heating	VR boiler	Geothermal combi heat pump
Ventilation	Natural ventilation	Balanced ventilation
Renewable energy production	None	38,4 m2 PV panels
Energy label	F	A++

Table 4.5 Applied measures Hof van Egmond (Nieman Bouwfysica, 2015[4])

Renovation Philipsdorp, Eindhoven

Philipsdorp is a neighbourhood in Eindhoven that was built between 1910 and 1923 to meet the need for living space for Philips' rapidly growing light bulb factory. The neighbourhood consists of 771 rental houses, which is mainly dominated by row houses and some semi-detached houses. There were over fifty different types of homes in Philipsdorp in Eindhoven based on different construction periods, shapes and sizes. From 2011, till 2018 these houses were renovated in four phases. The housing corporation 'Woonbedrijf' invested more than 100 million euros in total for the renovation of the houses. That includes additional costs such as research, fees, permits, implementation and social planning. On average it cost 134.500 euros per house. For the houses, one renovation strategy was used based on upgrading the buildings from the inside and replacing some building components. A collective insulation package was implemented for all the houses in order to go from label D, E and F to label A and B. This package included measures such as the insulation of exterior walls, insulation of the roof, applying HR++ glazing and adding mechanical ventilation (Nieman Bouwfysica, 2015[5]; Stichting Woonbedrijf, 2018).

Construction	Before the renovation	After the renovation
Floor	No insulation	Concrete floor (no insulation)
Walls	No insulation	75 mm mineral wool insulation (Rc value of 2,36)
Roof	No insulation	80 mm mineral wool insulation (Rc value of 2,86)
Windows	Single and double glazing	HR++ glazing (U value of 1,80)
Heating	VR and HR-107 boiler	HR-107 boilers if needed
Ventilation	Natural ventilation	Mechanical ventilation
Renewable energy production	None	None
Energy label	D, E, F, G	A, B

Table 4.6 Applied measures Philipsdorp (Nieman Bouwfysica, 20155; Stichting Woonbedrijf, 2018)

Renovation private houses, Dalfsen

In this renovation project a collective renovation approach was used for 53 houses which are privately owned. The houses consisted of the same type: row houses built in the 70's. The project was executed by a collaboration of the municipality, a consultancy bureau and the home-owners. The residents were encouraged to apply energy saving measures to their dwelling by:

- offering residents free energy advice-on-measure;
- giving resident guidance (personal attention);
- establishing a sustainability platform with local entrepreneurs and provide subsidy applications.

By convincing using a large-scale renovation approach, many individuals could be interested in saving energy in their homes in the short term. This approach made it possible to use a collective subsidy application for energy-saving measures. By using HR++ glazing and adding insulation in the roof, floors and cavity walls, an energy reduction of 20-50% could be realized[8] (Nieman Bouwfysica 2010).

4.3 Finding an optimal large-scale renovation strategy

As stated in chapter 1, the current building practice falls short to realize the energy transition in the building sector within the set period. When backcasting from 2050 to the current situation, the set goals will not be achieved in time with the current steps (Filippidou, Nieboer, & Visscher, 2017). In the context of this, more and more efforts are being made to renovate the existing housing stock on a large scale. In order to carry out these renovations on a large scale, an integrated approach is needed whereby whole neighbourhoods can be renovated in a short period of time (BPIE, 2013; Stroomversnelling, 2018). The examples in the previous paragraph show that various large-scale renovation strategies are used in renovation projects. Most strategies use common renovation principles such as replacing the existing structure, adding new components (inside and outside) or covering the existing structure with a new envelope. When looking at the project details it can be noted that a wide variety of renovation measures are used. Furthermore, almost all large-scale renovation projects concern the renovation of rental properties owned by housing corporations. Only the renovation project in Dalfsen focused on privately owned property. The question is why are the applied strategies and measures different for each project and what is the optimal strategy. This can be explained by various reasons, such as the ambition or goal of the project. Other aspects and parameters like the comfort requirements of the occupant, available funds, architectural state, type of building and construction can explain this as well. In this paragraph the process of finding an optimal large-scale renovation strategy is discussed. First of all, the decision-making process in general is elaborated (§4.3.1). Then the parameters which influence this decision-making are shown (§4.3.2).

[8] The specific details of the applied measures are unknown.

4.3.1 The decision-making process

The selection of an optimal large-scale renovation strategy is a complex process. Despite the various resources that provide advice on how to renovate a single building, the body of knowledge regarding key parameters affecting the decision-making process for renovations remains limited. In this paragraph, more insight is given regarding the decision-making process in renovation projects in general. This is based on literature, expert judgement and an interview. The selection process of a large-scale renovation strategy can be seen as a trade-off between the financial investment to implement that renovation strategy and the benefits obtained from the renovation (Jafari & Valentin, 2017; Ma, Cooper, Daly, & Ledo, 2012). These renovation benefits can be:

- economic (e.g., reducing energy consumption costs);
- environmental (e.g. reducing CO_2 emissions);
- or social (e.g. enhancing occupant's comfort and health) (Jafari & Valentin, 2017).

Improving the energy performance alone is rarely the main motivation for renovations. As stated by S. Hartwig:

"*Costs are the most important motive for renovations. Eventually, people renovate in order to save money, not because of sustainability*" (pers. comm. Hartwig, July 4th, 2018).

The decision-making for renovations for a single building usually comes from the owner or manager of the property. For a large-scale renovation however, the renovation is often initiated by a housing corporation, energy cooperative, municipality or consolidation of multiple private home-owners. The decision-making process is different, depending on the initiator. A single home-owner often renovates due to a needed replacement or functional upgrade, financial (reduced energy bill) or social motivators (increased comfort) (Konstantinou, 2014). For initiators such as housing corporations or landlords, large-scale renovations are initiated based on rational choices that are made on the basis of the organization's objective or goal. Objectives such as reducing the housing costs or improving the value of the property. In addition, these stakeholders have social objectives as well in addition to business objectives. There are always housing corporations that want to take a leading position by setting social objectives such as energy saving in the context of the sustainability process (Rijksdienst voor Ondernemend Nederland, 2009). Furthermore, certain covenants with local governments such as municipalities can play a role as well. For instance, an agreement, the 'Covenant rental sector' was made with the rental sector in 2012. According to this agreement the rental sector has to realize a housing stock with an average energy label of B or better by 2020 (Ministerie van Binnenlandse Zaken en Koninkrijkrelaties, 2012). In general these motivators are interconnected (Konstantinou, 2014).

The optimal strategy

Which large-scale renovation strategy is the most optimal, depends on various aspects. Improving the energy performance of the existing building on a large-scale is complex. In every renovation project, whether initiated by a housing corporation, municipality or home-owner, balance is sought. This is a balance between the most cost-effective renovation strategy, the required service levels and indoor comfort setting(Jafari & Valentin, 2017; Ma et al., 2012). The decision process of determining an optimal large-scale renovation strategy can be seen as a multi-criteria analysis of the various renovation objectives and possible measures constrained by the relevant decisive parameters (Agliardi et al., 2018). Rather than considering separate renovation measures (e.g. replacing windows or internal wall insulation), renovation measures should be applied as an integrated approach. As shown in Appendix IV, applying measures at building components affect each other, with regard to heat transmission. In order to improve the overall energy performance of a building, measures should be implemented as packages (Filippidou et al., 2017). As stated by Konstantinou et. al:

"An effective renovation strategy has to be long-term, target the deep transformation of the existing building stock, and to significantly improve its actual energy performance towards nearly zero energy levels. This level of energy saving typically requires a holistic approach, viewing the renovation as a package of measures working together" (Konstantinou, Guerra Santin, Azcarate-Aguerre, Klein, & Silvester, 2017).

Various technical, economic and social parameters are relevant for determining an optimal renovation strategy. However, this decision process is different when approaching multiple houses on a district scale (called 'large-scale renovation').

In large-scale renovations more, stakeholders are involved with different motivations and requirements. Stakeholders such as local governments and housing corporations. In addition, other bottlenecks and parameters play a role in the process. An optimal large-scale renovation strategy should consider these aspects. An effective large-scale renovation strategy has to engage the building owners and executing parties (e.g. housing corporations), as well as other relevant actors. Direct and indirect actors such as independent advisors, or a municipality can have an important separate role in large-scale renovations. Such as advising and encouraging owner-occupiers (Rijksdienst voor Ondernemend Nederland, 2009; Stroomversnelling 2018). In addition, the strategy should set out a long-term plan which can be transformational and dynamic. By assuming a desired final image (e.g. energy neutral in 2050) and then reasoning back certain renovation 'no-regret' measures can be assured. For instance, by considering the possible implementation of a heating network in the coming 5-10 years (Valk, 2016). In the end, a large-scale renovation strategy can be seen as a long-term strategy for improving the energy performance of multiple houses on a neighbourhood/district level. This requires a collective renovation approach, engaging the various relevant stakeholders and using a combination of passive and active measures (BPIE, 2013; Stroomversnelling, 2018; pers. comm. Slobbe, 2018). In this paragraph, the renovation strategies and key parameters which apply for large-scale renovations are discussed.

4.3.2 Parameters influencing the decision-making process

A renovation project is subject to many uncertainties like estimated energy savings, financial investments and changes in the consumption behaviour. The effectiveness of a renovation project is also dependent on information related to building-technical characteristics, such as the type of building, age, building installations, orientation, shape and size. Other important bottlenecks are related to household and socio-economic characteristics. Aspects such as the consumption patterns, type of ownership and comfort preferences (Guerra-Santin et al., 2018; Ma et al., 2012). The decision process for stakeholders such as housing corporations is defined by these parameters. Some parameters cannot be changed easily in renovation projects, such as the consumption behaviour, orientation and type of ownership. It is important to map these parameters. By identifying these parameters, the opportunities and bottlenecks can be determined in order to decide on the optimal large-scale renovation strategy. In this paragraph these parameters are explained. What should be noted is that most of these parameters are relevant for renovations both on a single- and large-scale. These parameters were identified based on an excessive literature review and expert judgement. In the following sections these parameters are elaborated (as shown in table 4.7).

Category	Parameter
Building characteristics	Building orientation
	Building envelope
	Shape and size
	Housing type and age
	Architectural state
	Energy performance
Socio-economic characteristics	Funds
	Life-cycle costs
	Scale and size renovation approach
	Ownership
Household characteristics	Comfort settings
	Household composition and consumption behaviour
Heat transition	Heat transition plan

Table 4.7 Key parameters influencing renovation strategies (Balkuv, 2017; Bommel et al., 2017; Konstantinou, 2014; Ma et al., 2012)

Building characteristics

The parameters elaborated in the following sections are associated with the building characteristics. In renovation projects, these are often the parameters which can be manipulated or changed.

Orientation

The orientation of the building, or the direction in which the building is faced (e.g. South-East), determines the amount of solar irradiance received. This is an important factor since it is directly related with the gained passive heat due to the direct sunlight. Depending on the orientation of the building, more or less heat is gained. Although the orientation of a building is given and cannot be changed, it is relevant for designing renovation strategies. Regarding the orientation of the building, the effects of renovation measures can be different. For instance, when a measure is sensitive for passive heat gains, overheating can occur and more ventilation and cooling is needed. In short, it is not only important for designing renovation measures which use solar energy (e.g. PV panels) it has to be considered as well to avoid overheating (Bommel et al., 2017; Konstantinou, 2014).

Building envelope

The building envelope is the entire building element that encloses the space of a building. It consists of the walls, floors, roof and windows. The design of the envelope, including the type of materials and insulation used, is one of the most influential aspects regarding the energy consumption and performance. Other characteristics can also indicate the potential improvement of the energy performance. Characteristics such as the thermal performance of the walls, windows, floors and roof. For instance, the proportion of the openings in a wall, which is referred to as the window-to-wall ratio (or WWR). This ratio shows how much surface of the façade is glazed. A high WWR (>40%) means that more than 40% of the total façade surface is glazed. This ratio is a key indicator in order to determine the characteristics of the building envelope, design and construction. As stated before, windows are a key building component which determines the amount heat that is lost and gained sunlight that enters the building. It is often the building component with the poorest thermal performance. If the WWR is rather high, then a renovation strategy could be focused on changing this ratio to reduce the heat losses or change the appearance of a building. However, this is not possible in all cases (Bommel et al., 2017; Konstantinou, 2014).

Shape and size

The shape and sizes in which houses are built affect the ratio between volume and façade surface of a house. The shape of a 'basic house' can be traced back to a basic rectangle with addition of a triangle. However, the existing housing stock is not that homogenous, often more complex housing forms are found. These shapes and sizes emerge often in the form of added spaces, for example an extension, or a dormer window. By adding these forms creates more façade surface in relation to housing content. According to studies these additions can be thermally unfavourable because there is more shared surface with the outdoor environment in relation to the content of the building. This causes greater thermal losses. In addition, too much complex shapes and bigger sizes can result in a more expensive renovation, since measures have to be customized to the specifications of the building (Bommel et al., 2017).

Housing type and age

The housing type refers to the archetype of the house. In literature and renovation projects these archetypes are often linked to the age, or construction period in which the house was built (e.g. detached houses built prior to 1945 or semi-detached houses built between 1965 and 1974) (Agentschap NL, 2011a). In the past decades, many changes have occurred in the techniques used and building requirements by laws and regulations. These changes reflect in the various types of housing and the energy performance of the houses. In the existing housing stock various types of houses can be found (Archidat Bouwinformatie, 2015). In the Netherlands, 30 archetypes of houses can be found which reflect the housing stock (Agentschap NL, 2011b). The renovation strategy differs between these types. A distinction in the strategy can be made between single-family houses (detached, semi-detached, row- and corner houses) and multi-family houses (apartments and flats). Single-family homes can relatively easily be changed individually, for instance, adding extra space horizontally or vertically. Only in the case of terraced houses (row- and corner houses) consent of a neighbour is needed sometimes, but in practice this is usually not a big problem. In the case of multi-family houses however, a somewhat radical individual change has collective consequences. Although technically expansion through a horizontal expansion is possible, it rarely takes place. In these cases, a more collective approach should be considered (Agentschap NL, 2011b; Rijksdienst voor Ondernemend Nederland, 2009).

The same distinction can be made when considering types of houses from different construction periods. There are major differences between the housing stock characteristics of various construction periods. In the table below, the required thermal performance of the building envelope is shown. As shown in the table, the required insulation values were lower in in the period between 1945 and 1974. After 1975 the requirements were tightened.

This can be explained by the attention for thermal bridges which started only after 1975. In addition, the requirements for glazing were tightened. After 1975 double glazing was required in living spaces with the exception of sleeping rooms, where single glazing still could be used. After 1992, the use of single glazing was completely terminated (Archidat Bouwinformatie, 2015; Agentschap NL 2011b; Rijksdienst voor Ondernemend Nederland, 2017a).

Insulation value	Minimum requirements Building Decree						
	<1945	1946-1964	1965-1974	1975-1991	1992-2012	2013-2015	>2015
Rc value wall [m2/K/W]	0,19	0,35	0,43	1,3	2,5	3,5	4,5
U value window [W/m2K]	5,2	5,2	5,2	5,2/2,9	2,9	1,8	1,65
Rc value floor/roof [m2/K/W]	0,15/ 0,22	0,33/0,39	0,17/0,86	1,3	2,5	3,5	3,5/6

Table 4.8 Building requirements past decades (Archidat Bouwinformatie, 2015; Agentschap NL 20112; Liebregts, 2011; NEN, 2014; Valk, 2011)

Considering the various thermal requirements according to the construction period, different renovation strategies can be used. For instance, since cavity insulation was not required until 1975, houses built before 1974 have a great potential for applying cavity insulation. Furthermore, the potential for applying insulation measures for houses built recently is rather low, since a good thermal performance is already present. On top of that, houses in residential districts were often built in series during the same construction period. Often a couple of types of houses can be identified in a district which can be used as a baseline for the renovation project (Nieman Bouwfysica, 2010; Rijksdienst voor Ondernemend Nederland, 2017a). By using the information, regarding the knowledge, construction methods and insulation requirements from that construction period, a relevant renovation approach can be developed for that building type. By upscaling this approach for all the houses categorized as the same type, a large-scale renovation strategy can be developed (Posad, 2016; Rijksdienst voor Ondernemend Nederland, 2017a).

Architectural design

The architectural design refers to the state and appearance of a building. These aspects have to be considered when designing a renovation strategy since it is not always possible to change this. This can depend on the requirements of the occupant. For instance, strategies such as add-ins and add-ons can change the appearance and functionality of a building. In some cases, applying renovation measures in the insight of a building can result in a reduction of the floor surface. The home owner has to consent to this. Other strategies, such as covering a new layer on the external components of a building can change the appearance of a building. In many cases, this is not possible when the building has a monumental status. For monumental buildings, the appearance of a building cannot be altered (Bommel,et al, 2017; Konstantinou, 2014).

Energy performance

The energy performance is another parameter which can be used to determine the potential for applying certain renovation measures. As stated in chapter 3, it is directly related to parameters such as the type of building, construction period, thermal quality and household characteristics. In the table below, the average insulation values of the building envelope are shown for each label category. This information is based on data from 5,000 existing houses. Every 5 to 6 years The Dutch Ministry of the Interior and Kingdom Relations carries out a large study on the energy performance of the existing Dutch housing stock. This research, called 'WoOn - Woon Onderzoek Nederland' or Housing survey Netherlands, is based on a survey which uses samples of the existing houses. This data provides information about the building characteristics such as user surface, housing type, and energy performance (Agentschap NL, 2011b).

Housing type	**Energy label and year of construction**										
	<1945	1946-1964	1965-1974	1975-1982	1983-1987	1988-1991	1992-1999	2000-2005	2006-2013	>2014	
Detached	G	F	D	C	C	B	B	B	A	A	
Semi Detached	G	F	D	C	C	C	B	B	A	A	
Corner house	G	F	D	C	C	C	B	B	A	A	
Row house	F	E	C	C	C	C	B	A	A	A	
Apartment	G	E	E	B	C	C	C	B	A	A	
Insulation value	**Minimum requirements Building Decree**										
	<1945	1946-1964	1965-1974	1975-1991			1992-2012			2013-2015	>2015
Rc value wall [m2/K/W]	0,19	0,35	0,43	1,3			2,5			3,5	4,5
U value window [W/m2K]	5,2	5,2	5,2	5,2/2,9			2,9			1,8	1,65
Rc value floor/roof [m2/K/W]	0,15/0,22	0,33/0,39	0,17/0,86	1,3			2,5			3,5	3,5/6

Table 4.9 Energy labels and minimum requirements insulation (Archidat Bouwinformatie, 2015; Agentschap NL 2011b; Liebregts, 2011; NEN, 2014; Valk, 2011)

The table shows that houses which were built before 1991 have a lower energy label than buildings which were built recently. This can be related to the building and insulation requirements which were applicable back then. Buildings with poor insulation lose more energy than buildings with good insulation. More heat loss results in a higher energy demand and consumption and thus a lower energy label (Konstantinou, 2014). Since the energy performance can be seen as a representation of these parameters, it can be used as an indicator for the possible improvements which can be made for a building. As shown in Appendix V, houses with a poor energy performance have a large potential for applying renovation measures, such as double glazing or cavity insulation.

Socio-economic characteristics

In this section, the parameters related to socio-economic characteristics of the housing stock are described.

Funds

Limiting factors on the willingness to invest are low savings potential (low gas consumption), a long payback period for investments in energy savings, and the lack of sufficient own financial resources. Although renovation measures can be cost-effective, the initial needed investments are an obstacle. Especially for single houses, the financial means is a major barrier. In addition, the costs of energy are often a small part of the household's expenditure. Therefore, it is often not the main reason for house-owners to invest in renovation measures. Furthermore, payback periods of renovation measures can be rather high and often subsidies are needed to make it financially interesting (ECN, 2013; Konstantinou, 2014).

For large-scale renovation the financial picture is completely different compared to renovations of single buildings. For single houses, the home-owner is often the one responsible for financing the project. For large-scale projects the financing is often done by a combination of actors such as housing corporations, home-owners or landlord. When considering the decision-process of large-scale renovations, the financial situation determines what kind of strategy is best (ECN, 2013). For large-scale renovation the different financial structure results in a two-sided bottleneck. Like single houses, there is often a lack of funding in housing corporations.

The implementation of energy-saving measures is mainly financed by corporations from rental income, with the help of a rent increase. One of the struggles is finding the right subsidies to make a feasible business case. In addition, there is a lack of funding of the residents as well (Kramer, 2016). Furthermore, there is a split-incentive. The problem is that the tenant has the benefits (improved energy performance), while the corporation has the burdens (investments). This problem is also referred to as the split incentive problem and is one of the most frequently mentioned problems with the corporations. When an owner (housing corporation) invests in a home the tenant receives the financial benefits of the lower energy costs. Many corporations want part of the return investment by increasing the rent or receive a percentage of the residents' savings. However, in social housing there is a certain maximum rental price, as stated in paragraph 3.1.4 (Rijksdienst voor Ondernemend Nederland, 2009). For housing associations, investing in energy-saving measures is financially less attractive since the corporation is not the one who receives the benefits. In the social rented sector, this would be more difficult, therefore specific financial solutions and regulations will be necessary. Measures with a low investment will be more interesting in this case (Itard & Meijer, 2008; Konstantinou, 2014).

Scale renovation approach

Another aspect is the scale advantage of large renovation projects. The planning and logistics plan what are formed for the execution of a large-scale renovation is highly dependent on scale. By increasing the scale and production, for example, a single housing block can be renovated be instead of a single dwelling. By using a large-scale approach constructor can reduce the costs of implementing renovation measures. The renovation of a single house in a district can be financially uninteresting. However, the renovation of this property can be interesting if the residential district is being renovated using one large-scale approach due to the economies of scale (Bommel et al., 2017; pers. comm. Hartwig, 2018).

Ownership

In terms of ownership, the existing housing stock can be categorized into three main types of ownership: owner-occupied, social rented, and private rented. In the Netherlands, approximately 57% of the existing houses belong to owner-occupiers, 29% are social-rentals, 10% is privately rented and the remaining and the remaining 4% are second homes or the owner is unknown (Rijksdienst voor Ondernemend Nederland, 2017a; Rijksoverheid, 2017a). For large-scale renovations often, different types of ownership are applicable in a project. The characteristics of the three sectors differ a lot.

In the social rental sector, the housing corporation is the owner of the houses, and the tenants of those houses, are the users. Both parties can take the initiative to take energy-saving measures. However, both actors have different requirements. For housing corporations or landlords, large-scale investments in energy-saving measures are rational choices that are made on the basis of the organization's objective. A great deal of attention is also paid to the costs involved in taking the measures and the speed with which these investment costs are earned back. The costs of the rent are the most important one. A rent increase is not easily accepted. However, the increase in comfort is also an important criterion among tenants (ECN, 2013; (Kramer, 2016). Another major obstacle for housing corporations to take energy-saving measures is the fact that a complex renovation approach is required combined with rent increases and cooperation from more than 70% of the residents. This 70% consent is not always easy to obtain. When residents are enthusiastic about taking energy-saving measures, this limit is reached earlier and the processes generally go faster. One of the starting points for increasing enthusiasm among residents is the housing cost approach. After all, energy costs are an increasing part of the housing costs. Another barrier is the split-incentive, as explained earlier (Kramer, 2016; Rijksdienst voor Ondernemend Nederland, 2009)

In the owner-occupied sector the investor directly profits from the investment, both in an improved energy performance and reduced energy costs. Although owner-occupants seem more sensitive to cost savings than tenants, they are scared back by the amount of investment (Rijksdienst voor Ondernemend Nederland, 2009; Stroomversnelling, 2018). Owner-occupiers are important in the energy transition process because the private sector is larger than the social and private rental sector. At the same time, it is the target group that is most difficult to reach. Usually the initiatives are taken separately per house, but in a few cases several owner-occupiers jointly take the initiative (Rijksdienst voor Ondernemend Nederland, 2017a). Municipalities and other authorities often take the initiative to induce owner-occupiers to take energy-saving measures. In contrast to the rental sector, the investor, in this case the owner of the house, is the one who profits directly from the investment. However, it is often harder to find sufficient funds.

In addition, it is harder to implement a large-scale renovation strategy in a district with mostly owner-occupied houses since consent is needed for every single house-owner. Studies show that owners of owner-occupied houses do not opt for a serial or large-scale approach, in which entire streets take the same measures. Owners of owner-occupied homes require customization: each owner decides on his own moment if and, if so, what measures should be taken (Rijksdienst voor Ondernemend Nederland, 2014; 2009).

Life-cycle costs

Another economic barrier is the life cycle costs of renovation measures. Although most economic decisions are often made on the basis of the initial costs and payback period, the life-cycle costs (LCC) is used in decision making as well. The life-cycle costs can be used to determine the initial investments and the benefits which are optioned in the future by the renovation measure over its service lifetime. The service lifetime of renovation measure can vary. On average, building installations and components such as window frames have a shorter lifespan than key components such as walls. HR-boilers for instance, have to be replaced every 10-15 years on average. Investing in these 'short-term' measures can be interesting when looking at the initial investment, however, when adding the costs of maintenance and needed replacements more 'long-term' solutions such as wall insulation can be more interesting (Jafari & Valentin, 2017)

Household characteristics

Although parameters such as the consumption behaviour and comfort settings of the occupant are important for a large-scale renovation project as well, other parameters such as ownership and income level play a more important role.

Comfort settings

With regard to comfort, occupants can have different requirements. Comfort can be seen as the well-being of a person, which is related to the health and external parameters such as the physical conditions of the house. Considering building related comfort settings, aspects such as the temperature setting, humidity, air quality lighting and noise hindrance apply. The conditions and perception of comfort can differ from person to person. Applying renovation measures can affect the level of comfort (Konstantinou, 2014; Majcen, 2016).

Household composition and consumption behaviour

As stated in chapter 3, the number, age and consumption behaviour of the occupants have a big impact on the energy demand. Only focusing on the building characteristics can result in an over- and underprediction of the energy demand, resulting in misleading energy reduction predictions of applied renovation strategies. Although aspects such as the age and number of the occupants cannot be changed, it does affect the needed energy and comfort requirements. In renovation projects, these aspects have to be considered. Furthermore, there are measures which can change the occupant's behaviour. For instance with the use of energy control systems (Ma et al., 2012).

Heat transition

An important aspect is the heat transition in the built environment. A lot is happening around this heat transition, such as the establishment of so-called 'heat transition plans' by local authorities.

Heat transition plan

The transition to 100% renewable energy and heating without natural gas brings major changes. Many municipalities and provinces are working to shape solutions to these challenges. From the central government, a new set of instruments is created for municipalities and provinces to give substance for this transition. One instrument is the heat transition plan. The heat transition plan is an important instrument that municipalities and regions can use to define the energy transition for their region. In a heat transition plan, a government indicates per neighbourhood and districts which alternative heat supply it expects in an area and when this has to be realized. The heat supply for a district can have spatial consequences, such as the implementation of district heating. The implementation of heat districts will play an important role in this heat transition plan. As shown in Appendix V, district heating is one of the possible renovation measures. For large-scale renovations, it is important to know what kind of plans are made by governments with regard to alternate heat sources.

This indirectly influences the optimal renovation strategy, since it determines to what extent houses should be renovated. For instance, if a low-temperature heating network will be implemented, houses have to be renovated to a very high energy performance standard. Considering the heat transition plans of a local government is an important aspect in determining the optimal large-scale renovation strategy (Ecovat, n.d.; Overmorgen, 2017).

4.4 Sub-conclusion

Renovations can be made according to different scales of interventions. In practice, it often means that structural and functional problems are solved and comfort-enhancing and energy-saving measures are taken. This thesis focuses on 'large-scale renovations'. This refers to improving the energy performance of multiple buildings on a large-scale (e.g. district level), by altering the building envelope, ventilation system and possible renewable energy production. This chapter tried to give insight into the parameters which influence the decision making for large-scale renovations. Various renovation measures can be taken in order to improve the energy performance. They can range from basic thermal improvements (such as cavity insulation) to more rigorous measures where the whole envelope is replaced. As stated in the previous sections, the decision-making process for stakeholders such as housing corporations regarding the improvement of the housing stock is a complex process. This process can be seen as a multi-criteria analysis of the various renovation objectives and possible measures constrained by the relevant decisive parameters. The decision-process for renovation projects include many bottlenecks such as changes in consumption behaviour, financial limitations and available subsidies. Furthermore, there are many other parameters which influence the decision making, such as the ability to change the appearance, existing insulation, building conditions and energy performance.

For large-scale renovations, this decision-making process becomes even more complex. As shown in paragraph 4.2 various renovation strategies are used in practice to improve the energy performance to a certain standard. When looking at these strategies it can be noted that the underlying principle is similar. In general, despite the renovation scale, strategies focus on replacing, adding or covering the building envelope by using a combination of passive and active measures. However, when looking closely the used measures differ broadly and widely. For instance, when looking at energy neutral renovation projects. In general, there is no 'universal' large-scale renovation strategy which can be applied to the entire housing stock. This can be explained by specific conditions of the existing housing stock and the set ambitions and requirements of the relevant stakeholders. Besides these building and household related characteristics, other parameters play a more important role. Aspects such as the type of ownership and collaboration between the various stakeholders. These uncertainties, in combination with parameters such as existing building characteristics, affect the decision-making process of an optimal large-scale renovation strategy. This decision-making process regarding the selection of an optimal large-scale renovation strategy can be defined as a trade-off between ambitions and requirements of the relevant actors (e.g. home owners and housing corporations), the financial investment needed and the benefits obtained from that renovation strategy. This strategy should include a long-term vision, constrained by the relevant parameters, such as existing building and household characteristics.

If all the key-considerations and parameters accounted in the decision-making are combined, an assessment framework for an optimal large-scale renovation strategy can be composed. This assessment framework, shown in Appendix VI, serves as a baseline for the elaboration of the model framework (chapter 5). In practice these considerations and parameters are important, however not all these considerations and parameters were processed into the models. As stated in chapter 2, the main focus lays on building technical characteristics, such as the energy performance and type of housing. However, in order to understand the process of the decision making in large-scale renovations, other aspects related to household characteristics had to be analysed as well. Chapter 5 elaborates which parameters are used and developed into the model framework.

5 DESIGNING THE MODEL FRAMEWORK

This chapter gives insight in the design approach for the models. In the following paragraphs the method is described how the various models were designed. In chapter 3 the term 'energy performance' was explained. In addition, the various calculation methods and models used in practice to determine the energy performance of buildings on a large-scale were elaborated. The various renovation measures and strategies found in literature and practice were shown in chapter 4. Furthermore, the bottlenecks and parameters influencing the decision making for renovation strategies were elaborated. The purpose of this thesis is to give insight into how the large-scale renovation strategy can be optimized with the use of a model. This model should predict the energy performance and propose suitable renovation strategies. Based on the literature review in chapter 3 and 4 a model framework was designed which incorporates the decisive energy performance parameters and large-scale renovation strategies. This gives an answer to sub-question 3:

- *How can the energy performance parameters and renovation strategies be implemented in a model to determine the optimal renovation strategy?*

In this chapter, the design approach of the model is described first (§ 5.1.1). The proposed model framework is based on a combination of a Geographical Information System (GIS)-tool and various models. In this thesis the following models and tools were developed:

1. GIS-tool;
2. Statistical energy performance predictive model;
3. Uniform energy performance predictive model;
4. Optimization tool.

The tools and models work in a sequential manner and use information both on the individual building level, as well as aggregated data. The results of the first 3 models are the input for the optimization tool. This information is assimilated per individual building and lifted to a larger scale (district level). In this way insight can be given regarding the energy performance of houses in a residential district and the possible optimal large-scale renovation strategies. The GIS-tool was developed in order to obtain specific building-related information on individual buildings, assimilated on a large-scale. The tool can derive key information such as the building type, construction period and surface area, which serves as input for the other models. This tool is explained in paragraph 5.1.2. Two energy performance predictive models were developed, in order to compare the different approaches. The first model uses a linear regression approach to predict the energy performance of individual houses on a large-scale. The second model uses reference values related to the energy demand, based on standardized building characteristics. Both models are discussed in paragraph 5.1.3. The optimization tool is used to select the various suitable renovation strategies on a large-scale. This is elaborated in paragraph 5.1.4.

5.1 Design approach

In this paragraph, the design approach of the models is described. The proposed model framework consists of two parts: one model that can predict the energy performance of individual buildings on a large-scale, and another model which can determine an optimal renovation strategy. In the following paragraphs a description is given of the methodology used to design these models.

5.1.1 Proposed model framework

This paragraph provides insight into the proposed model framework, which is based on a combination of multiple tools and models to support decision making for an optimal large-scale renovation strategy. The proposed model framework is based on the development of a GIS-tool, energy performance predictive model and an optimization tool. The framework uses various steps, as shown in figure VII.1 (Appendix VII).

The first step of the framework is the assimilation of the key data needed for predicting the energy performance of individual houses in an entire district. This is done via the use of a developed GIS-tool.

This tool gathers specific data on individual houses on a district or city level which includes data such as the type of housing, year of construction and user surface. Other data such as the number of occupants and average yearly gas and electricity consumption is derived from open databases. This is aggregated data derived from the Central Bureau of Statistics and energy providers. The energy performance predictive models use this dataset of the specific district to predict the energy demand of individual houses. Based on this predicted energy demand an estimation can be given of the energy performance. The optimization tool identifies potential large-scale renovation strategies that can be implemented based on key parameters such as existing construction, insulation values and year of construction. A dataset with widely used renovation measures was established as input. These renovation strategies are formulated based on possible renovation scenarios, such as maximizing the reduced energy consumption, minimizing costs or CO_2 footprint. This information is combined with data of key parameters such as the type of housing and energy performance of the individual houses. By assimilating and upscaling this information on a district level, a large-scale renovation strategy potential map can be generated. This map shows the potential of applying a certain strategy.

The initial purpose of the proposed model framework is to assimilate key information of individual buildings and lift this to a larger scale (e.g. district level). In this way insight can be given regarding the energy performance of houses in a residential district and the possible optimal large-scale renovation strategies. This information can be used for supporting stakeholders such as housing corporations, policy makers and governmental bodies such as municipalities in the decision-making process for renovations. In chapter 6 the proposed model framework is used for a case study to show how this could work and what improvements have to be made.

5.1.2 GIS-tool

Since there are no opensource data bases regarding the type of housing in the Netherlands a Geographical Information System (GIS) tool was made by the researcher to determine the type of housing. This tool is based on the method used by the Land Registry (In Dutch; Het Kadaster) as shown in figure XII.1 (Appendix XII). The Land Registry registers and provides information about the location of real estate in the Netherlands (Kadaster, n.d.).

To determine the type of housing the BAG (Basic Registration Addresses and Buildings) was used. The BAG is part of the Dutch government system of basic registers. Municipalities are responsible for including the data in the BAG and for its quality. Organizations with public duties, such as ministries, water boards, police forces, security regions and the Land Registry are obligated to use the authentic data from these records. The BAG uses the properties and type of accommodation of buildings, accommodations such as industry, offices, shops and residential functions (Kadaster, 2014). To determine the type of housing, the status and function of the building were used. Only buildings with a residential function were selected. Buildings with the status "unrealized building" and "property demolished" are not included as well. To determine the housing archetype, a number of preconditions have been drawn up. Houses can be selected in the GIS-tool based on these preconditions. The preconditions relate to the number of addresses and spatial relation to adjacent buildings. Table 16 shows the preconditions that apply in the tool. Although several sub housing types can be identified with regard to apartments, such as porch-houses and gallery flats, the GIS-tool is unable to do this. Due to the limitations of the software and data from the BAG, these types were consolidated as one type: apartments.

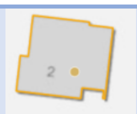
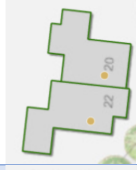
Typology	Precondition	Illustration
Detached	No adjacent buildings	
Semi-detached	Next to another adjacent building which has no adjacent building	
Corner house	At the end of a row house	
Row house	In between two adjacent houses	
Apartment	Has more than one address	

Table 5.1 Preconditions identification type of housing

5.1.3 Energy performance predictive model

In order to determine the optimal large-scale renovation strategy, insight is needed in the energy performance. The energy performance is one of the key indicators which can be used to determine the potential for improvement, with regard to renovations. A good energy performance indicates a low energy demand; realized by a good thermal quality of the building envelope. In this case, the potential for a renovation is rather low. Houses with a poor energy performance, on the contrary, have a higher potential due to the lack of proper insulation. In this study two energy performance, predictive models were developed. The predictive power of the two models is compared based on the case study (chapter 6). Firstly, a statistical model was used in order to predict the energy performance. This model is more complex, but if used correctly, can be more accurate. Secondly, a uniform model was developed to compare the predictive power of the statistical model. The uniform model predicts the energy performance based on reference values and building characteristics. These models only serve to create the input needed for the optimization tool. This input, the predicted energy performance per house of an entire district, is one of the key parameters used to determine the potential for applying a large-scale renovation strategy. The two models are elaborated in the following sections. For both models, parameters were used to determine the energy performance. These parameters were identified based on the literature in chapter 3 and expert judgement.

Statistical model

In chapter 3 a definition is given regarding the term "energy performance". In general, the energy performance can be expressed as the total amount of energy needed ($Qtotal$) to meet the energy demand of a building over a year. On an individual building level this can be expressed via the use of an energy performance indicator such as an energy label, energy index or energy performance coefficient. Although these indicators use different formulas (as shown in Appendix II), the energy demand ($Qtotal$) remains one of the key parameters in these calculations.

In order to predict the energy performance, a bottom-up statistical approach was used. In contrary to engineering approaches, statistical approaches require common and widely available data and can be used repeatedly, regardless of the case it is used for. Models using a statistical approach can be based on three different techniques: regression-, conditional-and neural network techniques (Swan & Ugursal, 2009). A comparison of the different techniques found in literature showed that the differences regarding the errors in the prediction are generally comparable. The statistical model described in this thesis uses linear regression. The advantage of using a linear regression technique is that it is rather easy to use and it is capable of using multiple parameters (Mastrucci et al., 2014; Swan & Ugursal, 2009).

Methodology

In order to predict the energy performance of individual houses on a district level, the total energy demand ($Qtotal$) must be known. As shown by the formulas in Appendix II, the total energy demand over a year is calculated by summing up the primary energy required for space heating, hot tap water, auxiliary electricity (pumps and ventilators) and lighting, and subtracting energy production from solar PV and cogeneration. The problem is, there is no publicly available data regarding the total energy demand per year of households on a district level. However, there is open data available of the yearly energy consumption related to gas (m3/year) and electricity (kWh/year) on an aggregated level (postcode areas). In order to go from this aggregated level to individual houses on a district level, a multiple linear regression model was used. This model predicts the energy demand based on historical consumption data, derived from network operators. With the use of this statistical approach, the energy demand can be determined for houses in an entire district.

The following sections present the used parameters and formulation of the linear regression model. These parameters and formulas were based on the current state of the art in literature, with regard to bottom-up statistical models. A summary of these models can be found in chapter 3. In chapter 7 the validation is described with the use of the test case. The statistical software program SPSS was used for this model. This statistical prediction model is based on the relation between energy demand and key parameters influencing this demand. As explained in chapter 3 there are various parameters which have a big influence on the energy demand. In the table below these parameters are shown.

Aspect	Parameters
Building characteristics	Year of construction
	Type of housing
	Surface area
	Building systems (ventilation and heating)
	Thermal/insulation performance
	Number of floors
	Compactness (ratio outer surface and volume)
Household characteristics	Income level
	Number of occupants
	Age of the occupants
	Consumption behaviour

Table 5.2 Parameters influencing the energy demand and performance (Aksoezen et al., 2015; Fonseca & Schlueter, 2015; Johansson et al., 2017; Kontokosta & Tull, 2017; Mastrucci et al., 2014)

Although all these parameters affect the energy demand, and thus the energy performance, not all parameters were used in the designed linear regression model. This has to do with the availability and quality of data. As stated in chapter 2, the proposed model should not be constrained by the available data. The model has to be applicable and repeatable in every situation, despite the case. Therefore, it has to use widely available open data. Until now, open data regarding figures about household characteristics such as the occupant's behaviour and age have not been available. This also accounts for the thermal performance and building systems present in individual buildings. The same applies to the thermal performance, the number of floors, compactness and the type of insulation applied.

The statistical model uses multiple linear regression to downscale widely available data regarding parameters related to the building and household characteristics. The Ordinary Least-Squares (OLS) method was used for this model. The set of parameters used in the regression model are shown in table 5.3. These parameters are required in order to get a reliable prediction of the energy demand. Although some of these parameters cannot be influenced or manipulated by a renovation, such as income level or the number of occupants, they have to be included in the statistical model. As stated in paragraph 3.1.5, household characteristics such as level of income and number of occupants are related to the energy demand.

Excluding this in the regression model will result in a less accurate prediction. Only using building characteristics can result in inaccurate predictions of the energy demand, and thus energy performance (Majcen, 2016).

Parameter	Description	Variable	Unit	Source
Building and household characteristics				
Surface area	Average surface area per house	Xfloor	m2	GIS-tool
Archetype house	The share of archetype per postcode area; 5 types of housing	Xtype	percentage (%)	GIS tool
Construction period	The share of construction periods per postcode area; 6 construction periods	Xcons	percentage (%)	GIS-tool
Number of occupants	Average number of occupants per household	Xocc	number	CBS PC6 data
Income level	Average fiscal income per month	Xinc	€	CBS PC6 data
Energy consumption				
Gas consumption	Yearly average gas consumption per connection	Ygas	m3	Data network operators
Electricity consumption	Yearly average electricity consumption per connection	Yelc	kWh	Data network operators

Table 5.3 Input data regression model aggregated on postcode 5 area

In this model the gas and electricity consumption are the dependent variables. The independent variables are the building and household characteristics. In order for the regression model to work, both dependent and independent variables have to be assimilated at the same data-scale. The energy consumption is based on aggregated data per postcode-5 area, therefore, the data related to the building and household characteristics have to be assimilated on the same level. The housing types were based on the archetype (e.g. detached, semi-detached). The constructing periods were defined according to the national classification: N.L. Agentschap, Voorbeeldwoningen 2011. In total 5 archetypes and 6 construction periods were defined. Resulting in 30 sub-housing types shown in the table below.

Typology	Construction period					
Detached	<1945	1946-1964	1965-1974	1975-1991	1992-2005	>2005
Semi-detached	<1945	1946-1964	1965-1974	1975-1991	1992-2005	>2005
Corner house	<1945	1946-1964	1965-1974	1975-1991	1992-2005	>2005
Rowhouse	<1945	1946-1964	1965-1974	1975-1991	1992-2005	>2005
Apartment	<1945	1946-1964	1965-1974	1975-1991	1992-2005	>2005

Table 5.4 Housing typologies (Agentschap NL, 2011b)

Formula

Given the surface area, type of housing, construction period, number of occupants and income level the gas and electricity demand can be predicted. The regression model predicts this as following:

$$Ygas = \beta gas + \beta type + \beta cons + (\beta floor \times xfloor) + (\beta occ \times xocc) + (\beta inc \times xinc)$$

$$Yelc = \beta elc + \beta type + (\beta floor \times xfloor) + (\beta occ \times xocc) + (\beta inc \times xinc)$$

The definitions of the variables in the formulas are shown in table 5.3. In this formula the β stand for the coefficients which are predicted by the regression model. Based on the gas and electricity predictions, the total energy demand can be calculated. The regression model predicts the end-use energy consumption required for the stated purposes in terms of final gas (m3/year) and electricity consumption (kWh/year). By converting this gas and electricity consumption into Megajoules per year and summing this up, the total energy demand ($Qtotal$) can be calculated. To make the step towards determining the energy performance, the following formula was used. This formula is based on the formulas used to determine the energy label and energy index for houses. In Appendix II more details can be found regarding the specific functions of the formula shown below.

$$ELG = 7 \times 0{,}84 \times \frac{Qtotal}{c1 \times Asurface + c2 \times Aloss + c3} + 2$$

In this formula, the ELG (in Dutch, Energy Label Number) can be related to the label class as used in the official calculation method for energy labels as shown in the table below. Using standardized geometrical form factors the transmission loss surface can be determined ($Aloss$). $Asurface$ stands for the transmission loss surface of the total user surface and is derived from the Basic Administration Buildings (BAG). The standardized energy consumption per m^2 user surface ($c1$), transmission loss ($c2$) and constant contribution to the reference energy use of existing buildings ($c3$) are derived from the current energy index calculation method (Nederland, 2014).

ELG	**Label class**
<10,6	A
10,6 - 11,8	B
11,8 -14,6	C
14,6 - 16,7	D
16,7 - 18,8	E
18,8 - 20,9	F
> 20,9	G

Table 5.5 ELG and related energy label (Gaalen & Staal-Guijt, 2014b)

Using this bottom up statistical approach results in an estimation of the energy performance per individual house on a district level. The lower the ELG and label class, the better the energy performance. The energy performance is indicated by the use of the energy label system. A low energy demand indicates a good energy performance (label class A and B). A high energy demand indicates a poor energy performance (label class C, D, E, F, G) (Rijksdienst voor Ondernemend Nederland, 2017a). The estimated energy performance is used as input, among other data, for the optimization tool (§5.1.4).

Uniform energy performance model

The application of a statistical regression model can be rather complex and is limited to the availability of opensource data. Ideally, a pre-set 'clean' dataset can be used for the statistical model. However, in reality information available about actual energy consumption and building characteristics can be limited. In addition, a lot of time is needed to process the available data in order to remove incorrect information. Therefore, a simple uniform was developed to compare the outcomes of the statistical model with a model which can be used easily and requires little data.

The calculation of the energy performance in the uniform model is based on key figures. For this, the most reliable and best applicable source in existing literature were used to assimilate reference values. Like the statistical model, the first step is to determine the energy demand. For estimating the energy demand per individual house on a large-scale, key reference values were used from the Vesta model made by the Dutch Environmental Assessment Agency from 2012 and the 'Uniform Benchmark Matrix Built Environment 2018' from the Dutch Expertise Center for Heat. The theoretically building-related energy demand in these models have been estimated on the basis of available information about comparable housing types, user surface, year of construction, functional energy demand (for hot tap water, space heating, cooling and electrical equipment) and the energy performance and efficiency of the buildings, the installations and the electrical equipment (Agentschap NL, 2018; Folkert, van den Wijngaart, 2012).

In total 30 key reference energy demand values were derived from these sources, based on the housing archetype (5 categories) and construction period (8 categories) as shown in Appendix VII. For every individual house, the theoretical energy demand is then based on the surface area and the type of house (based on construction period and archetype). A subdivision has been made between gas and electricity. It is important to mention that the theoretically building-related energy demand differs from the actual energy consumption. The theoretical energy consumption is calculated purely on the basis of house characteristics and installations. No account is taken of the behaviour of residents and the effects of climate. The gas consumption is largely building-related (space heating), but a considerable part of the electricity consumption (appliances) is not building-related. The theoretically building-related energy demand is calculated on the basis of models using standardized values, the calculated values may deviate from reality (Agentschap NL, 2018; Folkert, van den Wijngaart, 2012). By using this model, the total energy demand ($Qtotal$) can be allocated for individual houses. Using the same method as shown in the previous paragraph, the energy performance can be determined with the following formula:

$$ELG = 7 \times 0{,}84 \times \frac{Qtotal}{c1 \times Asurface + c2 \times Aloss + c3} + 2$$

5.1.4 Optimization tool large-scale renovation strategy

In this paragraph the optimization tool is discussed. The purpose of this tool is to give insight into the possible large-scale renovation strategies. This information can then be used by decision makers such as housing corporations, or municipalities to support the decision-making process for an optimal renovation strategy. The model uses the output from the energy performance prediction model(s) and the GIS-tool.

Methodology optimization large-scale renovation strategy

As stated in chapter 4 the process of selecting an optimal large-scale renovation strategy can be seen as a multi-criteria analysis of uncertainties such as financial limitations, key parameters such as existing building conditions and the financial investment needed in order to implement a certain strategy and the obtained benefits such as a reduced energy demand. The combination and variety of all these aspects make the decision process of an optimal renovation strategy very complex. There are a couple of studies that try to address all these aspects and parameters in optimization models such as an optimal investment budget in combination with life cycle cost (Jafari & Valentin, 2017), a multi-objective optimization focussing on economic benefits and increased comfort (Asadi, da Silva, Antunes, & Dias, 2012), or a tool to evaluate the environmental impact in terms of CO_2 emissions (Olsson, Malmqvist, & Glaumann, 2016). The purpose of this thesis is to propose a model framework which can incorporate all these parameters in order to aid in the process for deciding on an optimal large-scale renovation strategy. The optimization tool is based on a multi-criteria approach, developed in Excel. The tool combines the output generated by the GIS-tool and energy performance predictive models. This output is related to the building characteristics such as the type of housing, energy performance and existing construction. The developed model can be used to select the suitable large-scale renovation strategy for houses in a district level by:

1. considering all possible passive renovation measures per house;
2. selecting the optimal cost, energy performance or sustainable renovation strategy per house based on its existing building characteristics;
3. calculating a simple estimation of the potential energy reduction;
4. identifying the potential optimal large-scale renovation strategy for individual houses in a district level based on various renovation scenario's.

In the following sections, these 4 steps are elaborated.

1. Selection potential renovation strategies

The first step of the optimization tool is to identify potential renovation measures which can be integrated in a renovation strategy. As stated in paragraph 4.2.1, renovation measures can be divided into two categories: passive and active measures. Passive measures focus on minimizing the energy demand of the building. This can be realized by improving the thermal resistance of the building, increasing the airtightness and diminishing thermal bridges with the use of insulation measures. Active measures focus on the services of a building, which need the energy to operate. For example, services such as ventilation, lighting, heating and cooling. In practice the application of passive and active measures is applied in an integral approach.

Upgrading the thermal performance of a building with the use of improved insulation reduces the energy demand, the remaining energy demand is covered with the use of active measures such as heat pumps or solar PV (Konstantinou, 2014).

Although active measures are important in renovating the existing building stock and should happen in parallel with passive measures, they are not included in the first design of the optimization tool. The first design will focus on passive measures, which is the first step in order to reduce the energy demand. First of all, there is little to no available data on existing building installations such as the type of ventilation, boiler and lighting present on the individual household level. Therefore, it is difficult to determine the current inventory and potential with regard to these active measures for houses in a district level. Secondly, it is important to reduce the energy demand by means of passive measures first, before implementing active measures. This enhances the contribution of active measures. For instance, when looking at the application of heat pumps, a good thermal performance is needed for a heat pump to work efficiently. If a house is not or badly insulated then a heat pump has to work too hard and the efficiency is not favourable (Ecofys, 2016b). In addition, a large part of the energy reduction potential of existing houses lies in the application of passive measures as shown in Appendix V. Furthermore, the proposed model functions as a basic model in which additional measures can be applied later on, such as active measures.

The potential measures were selected based on a dataset which includes standard and common used passive measures which reduce the energy demand of houses. These measures were derived from literature, renovation projects and expert judgement. Each measure includes the insulation value, installation costs and CO_2 footprint. In the table below the measures are shown.

Building zone	**Renovation measure**	**R_c value (m^2/K/W)**	**U-value (W/m^2K)**	**Costs single/multi-family houses(€/m^2) [9]**	**CO^2 footprint (kg/m^2)**
Cavity wall	50 mm cavity insulation (EPS)	1,52		12,5/13,36	15,8
	50 mm cavity insulation (mineral wool)	1,47		20/21,38	6,41
	50 mm cavity insulation (PUR)	1,85		25/26,73	21,9
Internal wall	100 mm add in interior wall (rock wool)	2,78		82,5/88,19	12,82
	100 mm add in interior wall (EPS)	2,94		90/96,21	31,6
Internal roof	109 mm add in existing roof boarding (EPS)	3,50		40,46/43,25	34,44
	127 mm add in existing roof boarding (PIR)	5,00		49,26/52,66	55,63
	100 mm add in existing roof boarding (rock wool)	2,78		44,23/47,28	12,82
Glazing	Double glazing (HR++)		1,2	126,14/129,3	25
	Triple glazing (HR+++)		0,8	183,27/171,44	31,2
Floor	100 mm add in	3,70		25/26,73	21,9
	100 mm add in (EPS)	2,94		33/35,28	31,6
	300 mm add in (Ecochips)	4,05		23/24,59	94,8

Table 5.6 Renovation measures (Arcadis, 2017; Archidat Bouwkosten Online, 2018; NIBE, 2015; Woonwijzerwinkel, 2018; pers. comm. van de Wetering, 2018)

The values in table 10 are based on reference values, differentiated per measure based on the type of housing (single-family house versus multi-family dwelling); project-based size, and a standalone moment of execution. More information with regard to how these values were established can be found in Appendix VII. Based on the building characteristics such as the type of house and building conditions the potential measures are selected.

[9] The costs are indicated for single- (e.g. detached) and multi-family houses (apartments)

This is done under the precondition that the building component is suitable for applying renovation measures. These preconditions are shown in Appendix VII.

The type of house is a good indicator of the existing building conditions. Based on the housing type and the construction period, an indication can be given of the building conditions. As stated in paragraph 4.3.2, houses built before 1974 often lack proper insulation. Building regulations were rather weak in that period. Only after 1974 regulations were tightened. Until now there is no existing opensource dataset available regarding specific information of the existing insulation and building condition of individual houses. Therefore, a dataset was established with 30 reference houses based on the archetype and construction period as shown in Appendix VII. This dataset includes information such as the energy label, the existing building condition and insulation values. These reference houses were based on information derived from 'Voorbeeldwoning 2011 bestaande bouw', the 'Calculation method Energy labels and the former insulation requirements derived from the Building Decree from 1965 till 2015 (Agentschap NL, 2011a; (Gaalen & Staal-Guijt, 2014a). The dataset was benchmarked with the use of expert judgment, by professionals active the construction or built environment sector (as shown in Appendix I). The reference houses are shown in Appendix VII.

Based on these reference values, the potential for renovation measures can be selected or excluded. As stated in paragraph 4.3.2, the possible renovation measures which can be applied depending on the existing building conditions, such as the current insulation values of the envelope and the type of glazing. For instance, the potential for renovation measures for recently built houses is relatively low, since these houses already have a well insulated envelope. Old houses, in contrary, have a high potential. Although some renovation measures have been applied previously, most of the old housing stock contain very poor insulation. As shown in the assessment framework in Appendix VI one of the first steps in determining the optimal renovation strategy is to identify the possible measures, based on the existing building condition. By doing this, certain measures can be excluded. For instance, cavity insulation will not be applied to houses built after 1992. In general, good cavity insulation is already applied in these houses (Rijksdienst voor Ondernemend Nederland, 2017a; pers. comm. S. Hartwig, 2018; pers. comm. A. Assad, 2018; pers. comm. M. Ouwens, 2018).

2. Selection optimal cost, energy performance or sustainable renovation measures

The second step is to formulate the optimal renovation measure(s). As stated in chapter 4, there are a couple of key motivators for renovating the building stock. Depending on the relevant stakeholders, the following motivators apply: comfort, costs, energy performance and sustainability (e.g. CO_2-emissions). In general aspects such as comfort are more relevant for initiators such as single home-owners. The energy performance and sustainability aspect are often more important for municipalities and housing corporations. Nevertheless, the motivators are often interrelated (Konstantinou, 2014). The developed tool intends to incorporate these motivators in order to compare and select optimal renovation measures.

Although comfort is an important aspect, it was not included in the first designed model. Comfort is the well-being of a person based on their subjective perception of a number of external parameters and it is also related to the health of the occupants (Konstantinou, 2014). Due to its subjectivity, it is very hard to quantify in exact values. This falls out of the scope of this thesis. Costs or financial motives are very important. In addition, the financial investment is also seen as one of the main barriers for renovations. Extreme insulation measures can result in a greatly improved energy performance; however, they can be very costly. As stated in chapter 1, one of the main reasons for reducing the energy demand in the building sector is to reduce greenhouse gas emissions. Although this can be achieved through energy reductions, more and more studies show that the production stage is becoming increasingly significant with regard to the greenhouse gas emissions (Olsson et al., 2016; Pombo, Allacker, Rivela, & Neila, 2016). In the model, this aspect is referred to the CO_2-footprint and is measured in the amount of emitted CO_2 emissions due to the production of materials used in renovation measures.

After selecting possible renovation measures (step 1), the excel tool is used to select the optimal renovation measure based on the ambition or goal that is set. Since this ambition or goal is dependent on the initiator of the renovation, three possible renovation scenarios were considered.

These scenarios were based on the main sub-criteria for renovations found in literature:

1. Renovation strategy using the lowest investment budget;
2. Renovation strategy with the best energy performance measures;
3. Renovation strategy using measures with the lowest CO_2-footprint (Jafari & Valentin, 2017; Ma, et al, 2012; Rijksdienst voor Ondernemend Nederland, 2009; Konstantinou, 2014).

Based on the applied scenario, the optimal renovation measures are selected. The goal of the scenarios is to quickly and easily identify possible renovation strategies, compare them with each other and thereby make professionals aware of the many possibilities to save energy. Although the possible scenarios can be limitless, since the sub-criteria required in renovations can be endless, it serves as a baseline for the tool. Interesting scenarios can be worked out in detail by professionals using their own knowledge and expertise on the basis of the specific situation.

3. Calculating potential energy reduction

Based on the selected optimal renovation measure(s), the potential energy reduction is calculated. This is the reduced energy consumption potential needed for heating. As stated previously, the selected renovation measures are passive measures, such as improved insulation and glazing. As described in paragraph 4.2.1, passive measures focus on minimizing the heat losses and/or maximizing the heat gains, thereby reducing the energy demand. These measures do not directly affect the energy consumption related to aspects such as ventilation, lighting, electrical applications and required hot water use for showers. Furthermore, the reduced energy is indicated in the potential reduction of natural gas consumption. Natural gas is the most common source for space heating in the Netherlands, around 93% of the households use gas for space heating (Energieonderzoek Centrum Nederland, 2017; Rijksdienst voor Ondernemend Nederland, 2017a). Although other sources, such as electricity are used as well for space heating (e.g. using heat pumps), it is hard to determine which part of the predicted electricity demand is related to space heating. There are no existing data sources which indicate what type of heating system is present in houses. Therefore, it was assumed that the predicted electricity consumption was only related to the needed energy for lighting, electrical appliances and auxiliary electricity, not heating systems.

With the use of the No-regret Calculation Excel Tool, the new energy demand can be calculated per individual house for an entire district. This tool is based on a method that has been developed at the Dutch Energy Research Center (ECN) and later at the Dutch Organization for Applied Scientific Research (TNO). The energy saving potential is calculated based on the selected renovation measures (step 2) and predicted energy demand derived from the energy performance prediction models. The behaviour of the occupants and the effects of climate (actual energy consumption is lower in warm years than in cold years) is not considered (Energielinq, 2016).

4. Identifying optimal large-scale renovation strategy

In order to make the step towards identifying potential large-scale renovation strategies, other aspects and parameters have to be considered as well. Chapter 4 explained that the decision-making process for optimal large-scale renovation strategies can be seen as a trade-off between ambitions and requirements of the relevant actors (e.g. home owners and housing corporations), the financial investment needed and the benefits obtained from that renovation strategy. This trade-off is constrained by building and household characteristics, such as the consumption behaviour, building type and conditions. Nevertheless, other aspects such as the type of ownership scale-size of the renovation approach should be considered too. In deciding on an optimal large-scale renovation strategy, it is important to consider these various aspects, pre-conditions and characteristics. However, not all the relevant factors, determinants and parameters were integrated into the proposed optimization tool. First of all, like the energy performance predictive models, there is a limited amount of open data available. Until now, there is no open data with information such as the type of ownership and financial situation. This could be predicted or assumed based on statistical data, nonetheless, the proposed model focusses on building technical related characteristics at first. In order to give an indication of potential large-scale renovations strategies, the output derived from the various models and tools were combined and used in the GIS-tool to generate a large-scale renovation potential map. To find the most relevant opportunities for a large-scale renovation strategy, key parameters, related to building characteristics were considered. These were selected based on the literature review and expert judgment. Using the combination of this key information, houses can be clustered together based on their energy demand and saving potential, building type and energy performance.

By dividing these clusters into homogeneous categories, the potential for applying a large-scale renovation strategy can be identified. This is explained in the sections below.

Energy demand and saving potential

Before the savings potential can be determined, the energy demand of a building must be known. If this demand is high, it is interesting to look for opportunities for energy saving. If the energy demand of a single building is low, saving energy does not seem obvious. But if there is a large homogeneous cluster of buildings that use lot of energy together it can easily be addressed as an opportunistic target-group. Houses with high energy consumption and savings potential that are clustered together have a high potential for applying a large-scale renovation strategy. For these groups, an area-oriented approach can be designed. In some cases, there is a relatively high energy consumption, but there is hardly any savings potential. For instance, houses with a relatively good energy performance (energy label A, B). As stated in paragraph 4.3.2, houses with a relatively good energy performance tend to have better insulation. In this case, applying passive measures and improving the thermal performance of the building even more, will not result in much energy savings. In this case, it is more effective to look for alternatives, such as renewable energy production.

Building type

As shown in chapter 4, the building type (archetype and construction period) can be a good indicator of the building conditions. There are major differences between the housing stock characteristics of various construction periods. As shown in paragraph 4.3.2, the building regulations in the period between 1945 and 1974 were rather weak, as little attention was given to the thermal performance of buildings during this time. This can also be seen in the existing building conditions of these building types. Often no, or little insulation is present in walls, roofs and floors. Although many houses have replaced single-glazed windows with double glazing, still a lot of houses have single glazed windows (as shown in Appendix V). Therefore, there is still a lot of room for improvement for these building types. After 1975 the requirements were tightened. Considering the various thermal requirements according to the construction period, different renovation strategies can be used. For instance, since cavity insulation was not required until 1975, houses built before 1974 have a great potential for applying cavity insulation. This is less applicable for houses built after 1975, since there is already cavity insulation present. In addition, buildings that are considered as the same type are more suitable for applying a large-scale renovation. Due to the homogeneous building conditions, shapes and sizes less customization per house is required. As stated in paragraph 4.3.2, the houses in residential districts were often built in series in the same construction period. Often a couple of types of houses can be identified in a district which can be used as a baseline for the renovation project. By using the information, regarding the knowledge, construction methods and insulation requirements from that construction period, a relevant renovation approach can be developed for that building type. By upscaling this approach for all the houses categorized as the same type, a large-scale renovation strategy can be developed.

Energy performance

The energy performance serves as an indicator of how well a house performs energetically. The energy performance can be considered relatively low when the energy label is higher than C. As shown in table 4.9, a low energy performance relates to poor insulation. A relatively low energy performance has a very high potential for applying passive renovation measures. Measures such as improving wall insulation have a relatively low investment, with relatively high annual energy savings and thus a relatively short payback period. In these cases, the threshold for applying passive renovation measures is rather low. In contrast, the energy reduction potential for good performing houses tends to be lower since there is already a good insulation present. In addition, residents living in a house with a good energy performance or who already consume little energy are generally less willing to invest in energy-saving measures. In this case, alternatives such as active measures should be considered to provide a renewable energy source needed for heating, hot water use and electrical appliances. However, the investments for these measures are relatively high and can be financially uninteresting. For instance, investment of a solar collector is relatively high, while the annual savings are quite low, resulting in a long payback time (Rijksdienst voor Ondernemend Nederland, 2017a). Although active measures are not considered in the models, an indication can be given what the potential is for applying these measures in an integrated large-scale renovation strategy.

Based on these parameters a division can be made between a high and low potential for applying a large-scale renovation strategy. In the table below the categories are described. These categories are based on the potential for applying the steps of the trias energetica.

Phase 1 stands for the first step of the trias energetica; reducing the energy demand with the use of passive measures. Phase 2 stands for the second step; applying renewable energy resources with the use of active measures.

Category	Description
High potential phase 1	a promising target group, with a high energy demand, high energy saving potential and a poor energy performance (label C or worse)
Low potential phase 1	a target group, with a low energy demand, low energy saving potential but poor energy performance (label C or worse)
High potential phase 2	a target group, with a high energy demand, high energy saving potential and a good energy performance (label B or better)
Low potential phase 2	a target group, with a low energy demand, low energy saving potential and a good energy performance (label B or better)

Table 5.7 Categorization target groups

Using the output gathered from the previous steps and models a large-scale renovation potential map can be generated. The importance of this potential map is to know where houses with a high potential for energy savings are clustered, so an area-oriented large-scale renovation strategy can be designed. The opportunities that emerge from this map can provide the baseline for a large-scale renovation strategy or approach. In paragraph 6.3.2 an example is shown how this could be used, by applying the proposed models in a case study.

5.2 Sub-conclusion

The purpose of this thesis was to give insight into how the large-scale renovation strategy can be optimized with the use of a model. This model should predict the energy performance and propose suitable renovation strategies. As stated in chapter 1, the model should be easy to use and should be applicable for the whole Netherlands. Based on the literature review in chapter 3 and 4 and expert judgement a model framework was designed which incorporates energy performance parameters and large-scale renovation strategies. The proposed model framework is based on a combination of a GIS-tool an energy performance predictive model and an optimization tool. The tools and models work interchangeably and use information both on the individual building level, as well as large-scale (e.g. district level).

The GIS-tool was developed in order to obtain specific building-related information on individual buildings, assimilated on a large-scale. The derived data is used as input for the other models. Two energy performance predictive models were developed, in order to compare the different approaches. The first model uses a multiple linear regression approach to predict the energy performance. The second model uses key building related values of reference buildings. The energy performance predictive models use parameters related to building and household characteristics to predict the energy performance. Although the household characteristics, such as income and number of occupants are not used in the other tools and models, they were needed in order to get an accurate prediction of the energy performance. As explained in chapter 3, household characteristics are related to the energy demand. Excluding these characteristics will result in inaccurate predictions of the energy performance.

Based on the output from the GIS-tool and energy performance predictive model(s), an indication can be given of the baseline situation of individual houses on a district level. This information is used, in combination with other parameters such as existing building conditions and building type, in the optimization tool. The initial purpose of the proposed model framework is to assimilate key information of individual buildings and lift this to a larger scale (e.g. district level). In this way insight can be given in the energy performance of houses in a residential district and the possible optimal large-scale renovation strategies. This information can be used for support in the decision-making process for stakeholders such as housing corporations, policymakers and governmental bodies such as municipalities. In chapter 6 the proposed model framework is used for a case study to show how this could work and what improvements have to be made.

6 TESTING THE MODEL

In this chapter the case study is discussed. The case study was used in order to test the various tools and models. The importance of the case study is to analyse how the model works in practice. Furthermore, with the use of the case, it is possible to evaluate the accuracy of the energy performance predictive models. Based on this information the strengths and weaknesses of the designed tools and models can be studied. Additionally, key improvements can be detected regarding the accuracy and functionality of the tools and models. Moreover, the case provides input for the tools and models. The designed tools and models use location-specific parameters (e.g. building types in a certain district), which serve as the basis for the model framework. Without these parameters, the proposed model framework cannot be tested. The test case gives the input for the tools and models. By doing so, an answer can be given to sub-question 4:

- *What improvement does the test case provide regarding the designed model?*

The city of Eindhoven and the district 'Kerkdorp Acht' in Eindhoven, were selected as a case to test the use of the model(s). This city was chosen due to the available measured data regarding the energy consumption on the individual building level. This information was needed in order to test the accuracy of the linear regression model. On top of that, a large sample was needed for the statistical model in order to produce a reliable outcome. Like the bottom-up statistical models described in chapter 3, sample sizes were used ranging from 20.000 houses to 300.000 houses.
Furthermore, the city has representable building stock characteristics, compared to the average housing stock characteristic in the Netherlands. As stated in chapter 1, the proposed model should be applicable to the whole housing stock in the Netherlands. Therefore, a representable case was needed which included most of the commonly found types of housing and construction periods. Eindhoven and Kerkdorp Acht were found to have a representable building stock, in addition only measured energy consumption data per household could be found of this case. More information about the case study is described in paragraph 6.1.

First of all, the accuracy of the GIS-tool was analysed. Using aggregated measured data regarding the building types of the total building stock in Eindhoven, the predicted building types of the GIS-tool could be compared. This is elaborated in paragraph 6.2. Secondly, the energy (gas and electricity) demand and performance were predicted with the use of the statistical and uniform model. Measured energy data per household of the district Kerkdorp Acht was used to compare the predicted values of the statistical and uniform model. In addition, insight is given into the possible improvements of the designed tools and models.

6.1 Description case study

In this paragraph, the characteristics of the housing stock such as the housing typology and year of construction of Eindhoven are elaborated. In addition, the available datasets are addressed which were used in order to test the models. The location of the case study is shown in figure 6.1.

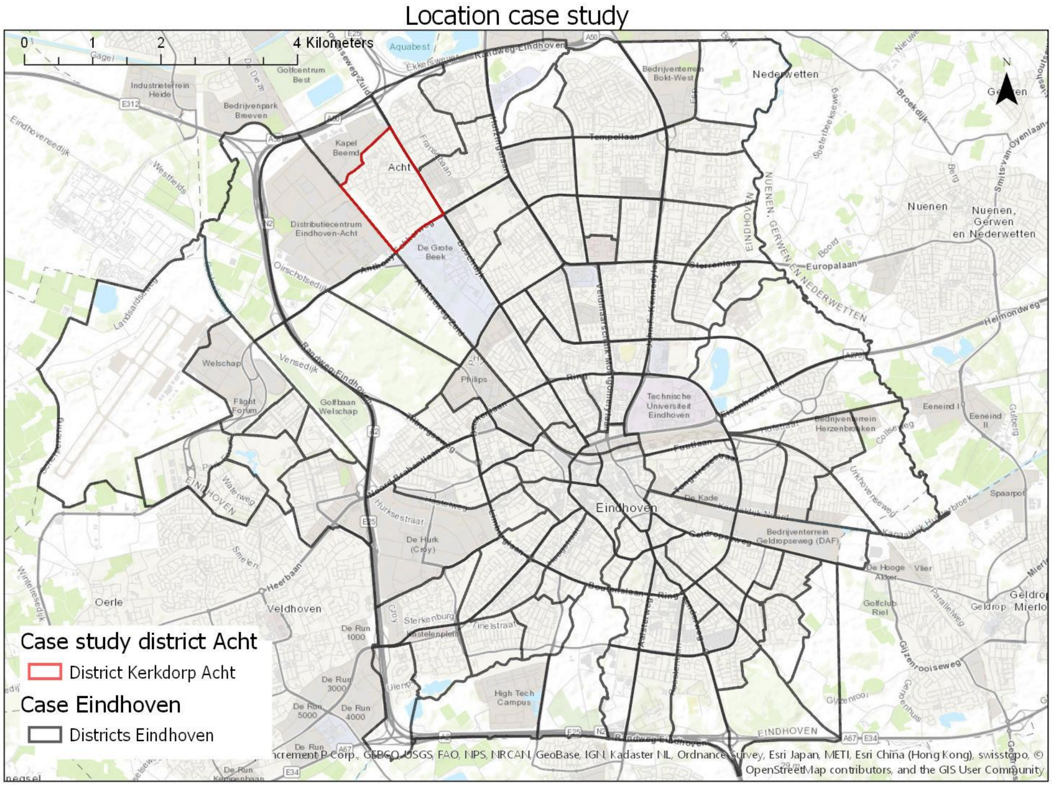


Figure 6.1 Research area case study

6.1.1 Available datasets

Building characteristics

At the start of 2017, Eindhoven had 106,873 houses. 48% of the housing stock in Eindhoven are owner-occupied. The remaining 52% are rental properties. These rental properties are largely owned by housing corporations (38%) and 14% is owned by private owners. 37% of the housing stock is a multi-family dwelling (flat, apartment, tenement house), the rest are single-family houses (detached, semi-detached, attached or terraced). 15% of the dwellings were built in this millennium (Gemeente Eindhoven, 2017). In the table below the characteristics of the housing stock is shown, compared to the total housing stock in the Netherlands.

	Share in stock (%)		
	Netherlands	Eindhoven	Kerkdorp Acht
Type of dwelling			
Detached	23	4	36
Semi-detached	19,6	21	42
Rowhouse and corner house	42,5	37	12
Apartment	15	38	10
Year of construction			
<1945	19	14	8
1945-1969	25	29	2
1970-1999	42	41	87
>2000	14	16	3

Table 6.1 Building characteristics Eindhoven compared to the average in the Netherlands, 2017 (Gemeente Eindhoven, 2017)

The building characteristics of the housing stock in the district "Kerkdorp Acht", consisting of 1.466 houses, is rather different compared to Eindhoven and the Netherlands. A large part of the houses was built between 1970 and 1999. Semi-detached and detached houses are the most common type of housing. Most of the houses (81%) are owner-occupied. A minor part is rental property (19%), which are largely owned by private owners. Only 4% of the rental properties are owned by housing corporations (Gemeente Eindhoven, 2018). Furthermore, a large part of the housing stock in the district is categorized as detached or semi-detached houses, which make up to 78% of the houses. Out of 1.466 houses, 391 have a registered energy label, as shown in figure IX.3 (Appendix IX). Most of the labels are C (41%). Other common labels are B (23%) and D (17%) (Rijksdienst voor Ondernemend Nederland, 2018). In the table below the energy labels per type of housing is shown.

	Registered energy labels						
Type of housing	A	B	C	D	E	F	G
Detached	6%	11%	5%	1%	1%	1%	1%
Semi-detached	0%	1%	1%	1%	0%	1%	1%
Corner house	1%	2%	2%	4%	0%	0%	1%
Row house	1%	10%	12%	8%	1%	0%	1%
Apartment	6%	0%	22%	3%	0%	0%	0%
Total	**13%**	**23%**	**41%**	**17%**	**2%**	**2%**	**2%**

Table 6.2 Registered energy labels Kerkdorp Acht (Rijksdienst voor Ondernemend Nederland, 2018)

Required inputs

Various datasets were used as input for the GIS-tool, the statistical and uniform model and the optimization tool. Data regarding the building characteristics such as year of construction, surface area and registered energy labels were extracted from the BAG and EP-online (database regarding registered energy labels). The type of housing was derived from the GIS-tool, in combination with the address and postal code. This data was available for every address in Eindhoven. In total, 71.790 buildings were derived from these datasets, consisting of 119.062 addresses and 380 postal code areas. In addition to this data, information about the number of occupants, income and measured energy consumption (gas and electricity) were gathered from the Central Bureau of Statistics (CBS) and energy suppliers. This data consisted of information at the aggregated level (5-digit postcode area). Historical gas and electricity consumption of the postal code areas of Eindhoven are the base of the regression model.

6.2 Results case study

This section shows the results of the case study. As stated previously, the case study had two functions:

a) delivering input for the construction of the tools and models;
b) testing the accuracy of the functionality of the tools and models.

First of all, the results concerning the GIS-tool are described (§6.2.1). With the use of this tool, the types of housing were identified in the whole city. The results are compared to actual figures of the city. In paragraph 6.2.2. the results of the statistical and uniform model are shown. The potential renovation strategies, in combination with the energy savings, costs and CO_2 emissions of the case study are elaborated in paragraph 6.2.3. Finally, the limitations and improvements of the designed selection model are described (§6.3).

6.2.1 GIS tool

With the use of the GIS-tool the various housing typologies were determined. In total, 71.790 buildings and 119.062 addresses were selected and attributed based on the method explained in chapter 5. In the figure X.I (Appendix X), the various types are shown of the entire city of Eindhoven. As shown in this figure, most of the houses in Eindhoven are row- or corner houses (shown in blue and black) or apartments (shown in red). In the outskirts of the city more detached or semi-detached houses can be found.

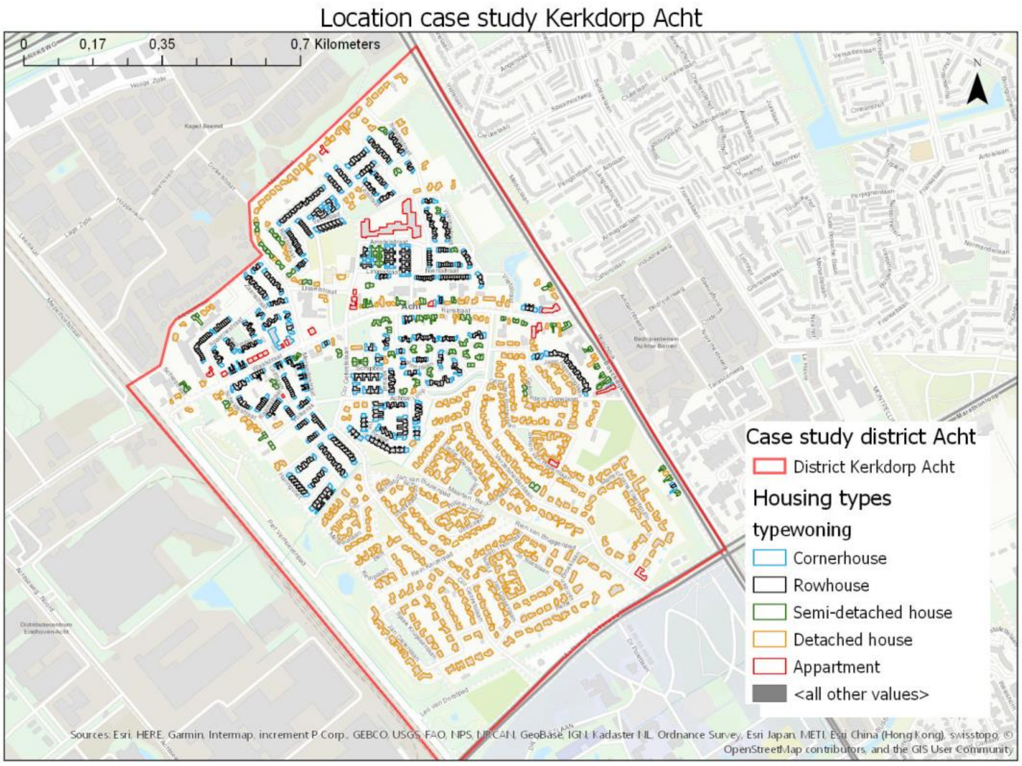


Figure 6.2 Various types of houses in Kerkdorp Acht based on the GIS-tool (enlarged map can be found in Appendix X)

The district Kerkdorp Acht has a total of 1.342 buildings and 1.478 addresses based on the GIS-tool. In total 5 archetypes can be defined (detached, semi-detached, etc.) and 27 sub-types based on the construction period as shown on the map in Appendix X. As shown in figure 6.2, most of the houses are detached. Other common housing typologies are row houses, corner houses and semi-detached houses. In table 24 the results are shown of the tool compared to measured figures from Eindhoven. The measured data only consists of archetypes, not type housing per construction period (Gemeente Eindhoven, 2017).

City of Eindhoven			
Archetype	GIS-tool	Measured data	Percentage off (%)
Detached	4.313	4.263	+1,17
Semi-detached and corner house[10]	18.944	23.026	-17,73
Rowhouse	52.757	40.468	+30,58
Apartment	42.962	40.925	+4,98
Total	**119.062**	**108.682**	**+9,55**
Case Kerkdorp Acht			
Type of house	GIS-tool	Measured data	Percentage off (%)
Detached	521	530	-1,70
Semi-detached and corner house	346	616	-43,83
Rowhouse	454	177	+156,50
Apartment	148	143	+3,50
Total	**1.469**	**1.466**	**+0,20**

Table 6.3 Results type of houses GIS-tool and measured data 2017 (Gemeente Eindhoven, 2018; 2017)

When comparing the results, it can be noted that especially semi-detached, corner houses and rowhouses differ from the measured data. Detached houses and apartments are identified more accurately.

[10] In the registered data of Eindhoven, semi-detached and corner houses are aggregated as 'one' building type. Therefore, the determined semi-detached and corner houses by the GIS-tool were combined as well.

Especially in the case "Kerkdorp Acht", a lot of houses are identified as rowhouses with the use of the GIS-tool, while these should be semi-detached buildings. These differences can be explained due to inaccuracies and incorrect information from the BAG. Such an example can be shown in the figure below. According to GIS-tool, the two marked buildings are distinguished as a corner house (21) and a rowhouse (23). In reality, it can be noted that the two houses are categorized as semi-detached. This can be explained due to the fact that the BAG cannot make a distinction between constructions such as garages or sheds which are connected to the house. Therefore, a lot of houses are distinguished as rowhouses or corner houses, while in reality these should be identified as semi-detached houses.

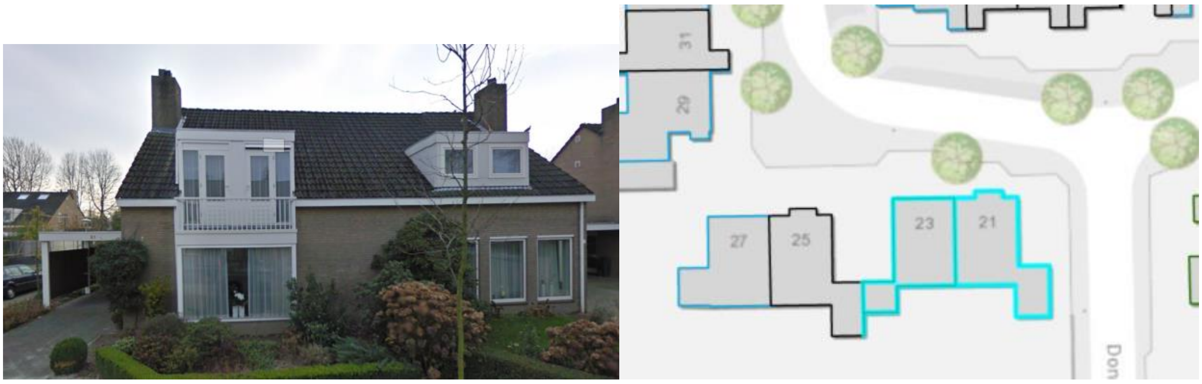


Figure 6.3 Example Amerlaan 21 and 23 (Google Maps, 2009)

Another example can be seen at the Eckartseweg Zuid, 388. The GIS-tool identified the house as an apartment, due to the multiple (duplicated) addresses present in the building. In reality, the house can be recognized as a row house. Changes in the address registry can occur in the BAG and result in duplicates.

Figure 6.4 Example Eckartseweg Zuid 388 (Google Maps, 2016)

The opposite can also happen. When addresses are missing in the BAG, the GIS-tool identifies buildings as detached when no adjacent buildings are present. However, as shown in figure 6.5, the building can be identified is an apartment.

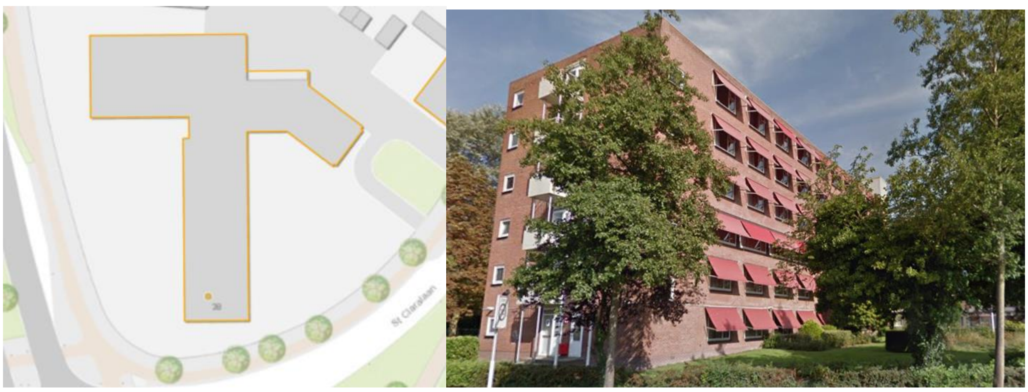


Figure 6.5 Example Sint Claralaan 38 (Google Maps, 2017)

In some cases, incorrect information from the BAG resulted in inaccurate predictions of the surface area. Such an example can be shown in the figure below, where the GIS tool indicated the building has a user surface of >4.000 m^2. However, in reality, it turns out that the biggest part of the building is a greenhouse.

Figure 6.6 Result GIS tool (left) and actual building (right) (Google Maps, n.d.)

6.2.2 Energy performance predictive model

In this sub-paragraph, the results of the two energy performance prediction models are elaborated. At first, the outcomes of the linear regression models are discussed, then the uniform energy performance model. The predicted outcomes of both models are compared to the actual gas and electricity figures provided for the district 'Kerkdorp Acht'.

Statistical model

The statistical linear regression model was applied to the entire housing stock of Eindhoven. The predicted outcomes were compared with actual measured data of individual houses, of the district Kerkdorp Acht. The measured data consisted of the yearly energy consumption (gas and electricity) from 2010. The required input for the statistical model was gathered from the GIS-tool, the yearly average gas and electricity consumption on a five-digit postal code zone derived from Enexis and Endinet, and household data derived from CBS. In total, data was gathered from 119.062 addresses and 380 postal code areas[11]. A more detailed overview of the results from the regression models can be found in Appendix X.

The yearly gas and electricity demand was then predicted at the individual household level using the results from the regression model. The estimated coefficients, *p*-value and standard error for the gas and electricity demand are shown in table 6.4 and 6.5. According to the regression model, 39,80% (R^2= 0,398) of the variability regarding the predicted gas demand can be accounted for by the regression model. This value is comparable to other studies (Guerra Santin et al., 2009; Mastrucci et al., 2014). When looking at the significance, it can be noted that most of the variables are found to be statistically significant (>0,1). Most of the predictors have a p-value below 0,05. A couple of variables are insignificant (<0,1): semi-detached houses, apartments and construction periods. 1946 - 1991. On top of that, two variables, row houses and construction period 1965-1974, were dropped out of the model to avoid perfect-multicollinearity drawbacks. This could be explained due to a couple of reasons. First of all, as shown in the previous paragraph, the GIS-tool results in inaccurate predictions of semi-detached, row and corner houses. On a city level, this can differ up to 30% (as shown in table 6.3), however when looking at a district level, predictions can vary up to 156%. Furthermore, with regard to apartments, 3 sub-types can be identified in the existing housing stock as stated in chapter 3. Sub-types with different building characteristics and energy performances. However, the GIS-tool cannot make a distinction between these subtypes and aggregates these types into one archetype: apartments. These inaccurate predictions of the types of housing can explain the insignificant variables. Furthermore, the derived dataset of the average gas- and electricity consumption per postcode area was incomplete. Some values were missing. On top of that, this dataset only consisted of data of one year. A follow-up study could provide more insight into the exact explanation of the dropouts and insignificant variables.

[11] This data is not included in the Appendixes, due to the sheer size of this dataset. However, they can be shared upon request.

Variables	Coefficients	Standard error	T value	*p*-value (significance)
(Constant)	628,704	226,119	2,780	0,006
Occupants	-100,011	55,583	-1,799	0,073
Surface area	2,876	1,220	2,358	0,019
Income	0,196	0,044	4,492	0,000
Detatched	943,843	265,701	3,552	0,000
Semi-detached	71,555	252,558	0,283	0,777
Corner house	1263,216	439,728	2,873	0,004
Apartment	269,365	195,667	1,377	0,170
Construction period <1945	296,327	96,269	3,078	0,002
Construction period 1946 - 1964	127,336	88,771	1,434	0,152
Construction period 1975 - 1991	-128,800	97,300	-1,324	0,186
Construction period 1992 - 2005	-299,371	139,065	-2,153	0,032
Construction period >2005	-459,691	159,191	-2,888	0,004

Table 6.4 Results regression model gas demand (R2 =0,398)

The electricity prediction model is less significant. Although the R^2 value is quite similar (0,37), also compared to other studies (Mastrucci et al., 2014), most of the housing types were found to be insignificant (table 6.5). In contrast to the gas model, only apartments have significant relation with the electricity demand, in combination with the user surface and fiscal income. Furthermore, row houses were dropped out of the model to avoid perfect-multicollinearity drawbacks. This could be explained due to a couple of reasons. The first reason is the that the large difference could be attributed to the accuracy of the input, as well as to the standardization of type of housing in the GIS-tool. As shown in paragraph 6.2.1, the GIS tool occasionally allocates a wrong type of house. This could explain the low significance of some predictors, regarding the type of housing. The second explanation can be related to the variability of the consumption behaviour of the occupants. This is not accounted for in the regression model. Furthermore, the electricity demand is also less subject to the building characteristics and more to the occupant's behaviour as explained in chapter 3.

Variables	Coefficients	Standard error	*T*-value	*p*-value (significance)
(Constant)	784,645	573,906	1,367	,173
Average number of occupants	-25,045	144,314	-,174	,862
Average floor area	17,289	2,795	6,186	,000
Fiscal income	,187	,095	1,968	,050
Detached	214,126	606,410	,353	,724
Semi-detached	293,285	682,286	,430	,668
Corner house	62,589	1206,923	,052	,959
Apartment	895,545	384,906	2,327	,021

Table 6.5 Results regression model electricity demand (R2 = 0,370)

The comparison of the predicted and measured data for both gas and electricity are shown in the figures below. In 36,40% of the cases the gas consumption was predicted within 20% error of the measured data. For 63,59% of the cases, the predicted values deviated more than 20% of the measured data.

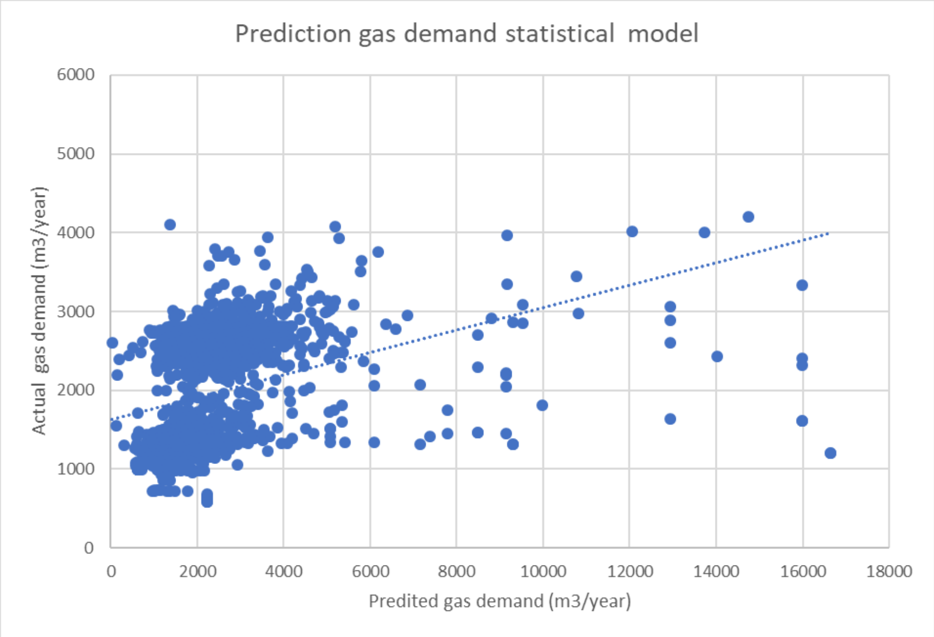


Figure 6.7 Results predicted gas demand by the statistical model, 2010

In the figure below the predicted values for the electricity demand are compared with the measured values. Of the predicted values, 66% deviated more than 20% of the measured values.

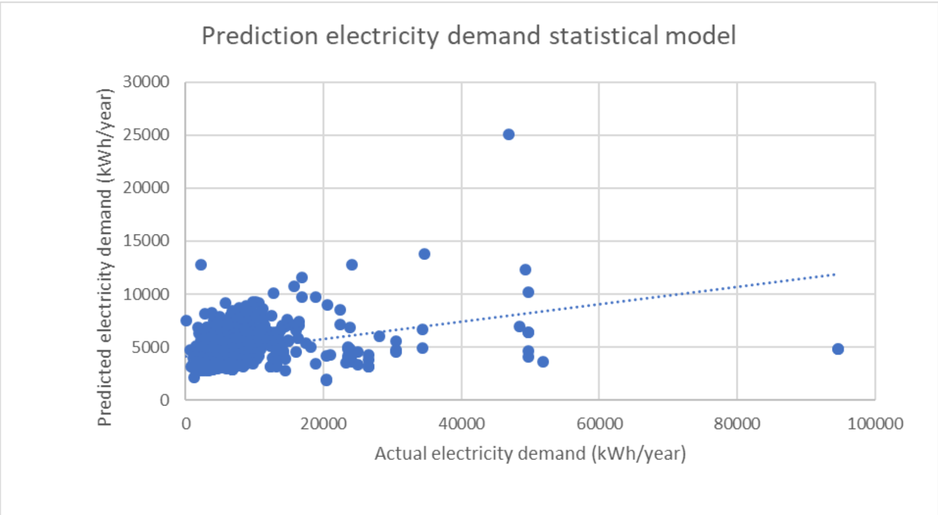


Figure 6.8 Results predicted electricity demand by the statistical model, 2010

This large difference in the predicted energy demand can be attributed to the accuracy of the datasets as well as the variability of building characteristics and consumption behaviour. Another explanation could be the rather small observations of the test case. The regression model was used for the whole building stock of Eindhoven. However, the predicted values of the statistical model were only compared to the measured data of only 1.467 addresses, while the regression model predicted the values of 119.062 addresses. Using a larger dataset of measured values could result in less deviation between predicted values and measured values. Using the method, as described in chapter 5, the energy performance can be indicated for individual houses for the entire district. The results are shown in the energy performance map in Appendix X. As shown in the map the energy performance in overall is rather good (A and B). A couple of houses have a bad performance (C, D, E, F and G). As shown in the map in appendix X, these houses are rather old. Most of these houses were built before 1936. Old houses tend to have a higher energy demand and poor insulation.

Uniform energy performance model

For the 1.467 houses in Kerkdorp Acht the gas and electricity demand was predicted based on the reference values and types of housing conform the developed uniform model. In appendix X the predicted gas and electricity demand for the individual houses in the district are shown. These results were compared with actual measured data.

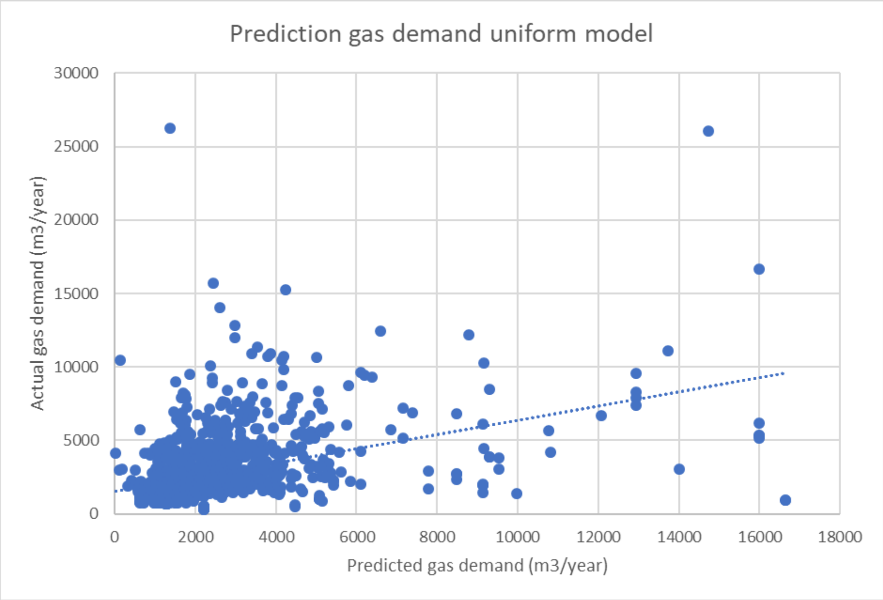


Figure 6.9 Results predicted gas demand by the uniform model, 2010

As shown in the figure above, more than 71,41% of the predicted gas demand values deviated more than 20% of the measured values. This is higher than the predicted values by the regression model. This can be explained by the fact that the uniform model uses reference values per dwelling type. These values are based on national key figures that are assigned to buildings on the basis of specific construction characteristics. Interventions that have already been done at building level are only based on national averages in processed. In addition, these reference values are calculated based on average demand behaviour (hot tap war usage, average room temperature, etc). The comparison with the electricity demand shows that the uniform model has similar results as the statistical model. For the electricity demand, 61% of the predicted values deviated more than 20%. This is 5% lower than the predicted values of the statistical model.

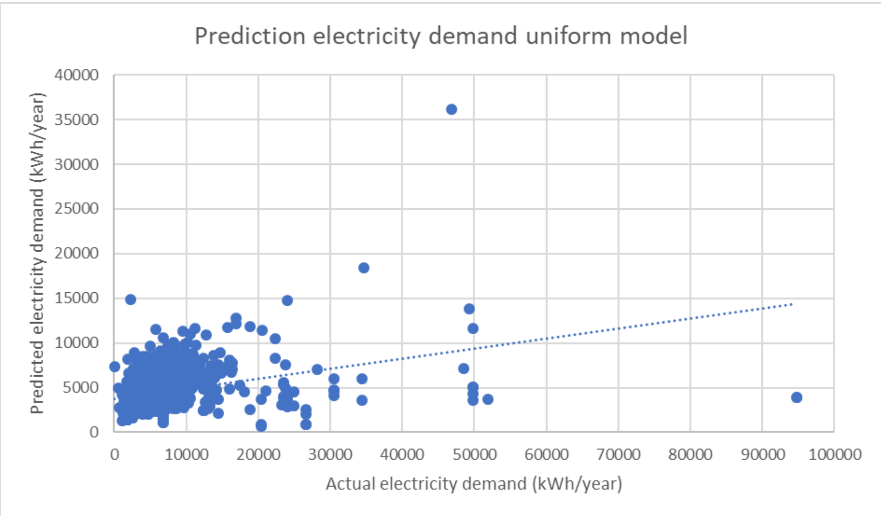


Figure 6.10 Results predicted gas demand by the uniform model, 2010

The energy performance is derived from the predicted the gas and electricity demand and building characteristics using the method as described in chapter 5. The results are shown in the maps in Appendix X.

6.2.3 Optimization tool

In this paragraph, the results of the optimization tool are shown[12]. Based on the derived output from the GIS-tool (building characteristics), and the energy performance predictive models (energy demand and performance), three renovation scenarios were examined for the district Kerkdorp Acht. By using the optimization tool, the following scenarios were processed for the district:

- Scenario I - optimal energy performance;
- Scenario II - minimum investment budget;
- Scenario III - minimum CO_2 footprint.

At first, the current building conditions of each individual house was determined with the tool. Based on the methodology as explained in in paragraph 5.1.4, the baseline conditions were determined. Using the derived building characteristics from the GIS-tool, such as the building type and construction period, the thermal conditions were determined, using the reference values as shown in Appendix VII. Secondly, for each scenario an optimal set of passive renovation measures was determined by the tool in order to improve current building conditions to the minimum building standards for an energy neutral building. In this selection the existing building conditions were considered in order to filter out irregularities. Furthermore, the measures were selected based under certain preconditions as shown in Appendix VII. For instance, no cavity-insulation was selected as a measure for houses built after 1991. Cavity insulation is already present in these houses (Rijksdienst voor Ondernemend Nederland, 2017a). The tool selected the renovation measures needed to reach this minimum required insulation standard. Based on the optimization tool, the impact of each scenario was determined in terms of energy saving potential, costs and the CO_2-footprint of the specific renovation measures, individualized for each house in Kerkdorp Acht. In order to make the step for identifying the potential for large-scale renovation measures, the houses in the district were clustered based on the categories as described in paragraph 5.1.4. By combining key information such as the potential energy reduction, energy performance and building type the potential for applying large-scale renovation was identified. The results of the scenarios are shown in a sequential manner.

Scenario I

For scenario I the optimal strategy was set at the optimal energy performance. Therefore, the passive measures were selected which have the most influence on the thermal performance[13]. Measures such as cavity insulation with PUR, EPS panels on the internal walls, PIR elements for the roof and triple glazing were applied to the houses. The insulation values, costs and CO_2 footprint per material are shown in the table below.

Measure	R_c value ($m^2/K/W$)	U value ($W/m^2/K$)	Costs (€/m^2)	CO_2 footprint (kg/m^2)
Wall cavity (PUR)	1,85		25	21,9
Wall (interior) (EPS)	2,94		90	31,6
Roof (PIR)	5		49,26	55,63
Glazing (HR+++)		0,8	171,44	31,2
Floor (Ecochips)	4,05		23	94,8

Table 6.6 Insulation values applied measures scenario I

The average investment budget for applying all these measures per building is €37.448,07. On average this results in a reduction of 45% of the total energy demand and a CO_2 footprint of 27,65 tons per house. Looking at the potential energy reduction of the entire district in Appendix X, it can be noted that most of the energy can be saved at detached houses and very old and poorly performing houses. What is interesting is that most of the detached houses have a rather good energy performance as shown in Appendix X.

[12] This chapter shows the key results. Due to the size and cryptic structure of the dataset, it was not included in the Appendixes. The exact overview of the calculation matrix and results can be shown upon request.

[13] The thermal resistance is measured with the Rc- and U-values. How these values work is explained in Appendix XI.

Despite the rather good energy performance still, a lot of energy can be saved by applying renovation measures. This can be explained by the rather high energy demand, as shown in Appendix X. Although this sounds surprising, the literature review can confirm this. In paragraph 3.1.5 this is explained by a study of the performance gap by Daša Majcen. This study showed that even in very good performing houses, actual energy consumption often is underpredicted. The rebound effect and a high indoor temperature play an important role in this discrepancy (Majcen, 2016). The opposite effect can also be explained for rather poor performing houses where the energy saving potential is rather low (<40%) as shown on the map in Appendix X. Although the energy reduction potential is rather low, quite a few of these houses have a rather poor energy performance. The low energy reduction potential can be explained by the rather low energy demand as shown in the maps in Appendix X. This could be related to the pre-bound effect. Which describes the effect of the underprediction of the energy demand in houses with a poor energy performance. In general, households tend to be more energy efficient and pay more attention to saving energy in poor performing houses to save money (Majcen, 2016).

Scenario II

For scenario II the optimal strategy was set at the lowest investment budget. The selected measures and the corresponding insulation values, costs and CO_2 footprint per material used for this scenario are shown in the table below.

Measure	R_c value ($m^2/K/W$)	U value ($W/m^2/K$)	Costs (€/m^2)	CO_2 footprint (kg/m^2)
Wall cavity (EPS)	1,52		12,5	15,8
Wall (interior) (rock wool)	2,78		82,5	12,82
Roof (EPS)	3,50		40,46	34,44
Glazing (HR++)		1,2	129,3	25
Floor (Ecochips)	4,05		23	94,8

Table 6.7 Insulation values applied measures scenario II

The average investment budget for applying all these measures per building is €32.187,22. On average this results in a reduction of 39% of the total energy demand and a CO_2 footprint of 21,02 tons per house. Although the potential in energy savings is lower than scenario I, most of the energy can be saved in the same target groups: detached houses and very old and poor performing houses. Looking at the energy saving potential map (appendix X) it can be noted that the energy saving potential for very poorly performing houses is similar to scenario I.

Scenario III

For scenario III the optimal strategy was set at the lowest CO_2 footprint. The selected renovation measures are used are shown in the table below. The average investment budget for applying all these measures per building is €32.923,61. On average this results in a reduction of 37% of the total energy demand and a CO_2 footprint of 14,04 tons per house. When looking at the potential energy reduction per house in the map in Appendix X, it can be noted that most of the potential is rather low compared to the other scenario's. Most of the houses have a reduction potential below 40%. The very old and poorly performing houses, however, still have a large energy reduction potential, which is similar to the other scenario's.

Measure	R_c value ($m^2/K/W$)	U value ($W/m^2/K$)	Costs (€/m^2)	CO_2 footprint (kg/m^2)
Wall cavity (EPS)	1,52		12,5	15,8
Wall (interior) (rock wool)	2,78		82,5	12,82
Roof (EPS)	3,50		40,46	34,44
Glazing (HR++)		1,2	129,3	25
Floor (Ecochips)	4,05		23	94,8

Table 6.8 Insulation values applied measures scenario III

Comparison scenarios

In the table below the various applied renovation measures are shown in relation to the total costs, reduced energy consumption CO_2 footprint. As shown in the table below, the three scenario's result in quite different renovation measures, which the model selected.

Renovation measure	Scenario I	Scenario II	Scenario III
Cavity insulation (EPS)		x	
Cavity insulation (mineral wool)			x
Cavity insulation (PUR)	x		
Adding additional wall insulation on the internal wall (rock wool)		x	x
Adding additional wall insulation on the internal wall (EPS)	x		
Adding additional insulation on the inside of the existing roof boarding (EPS)		x	
Adding additional insulation on the inside of the existing roof boarding (PIR)	x		
Adding additional insulation on the inside of the roof boarding (rock wool)			x
Double glazing (HR++)		x	x
Triple glazing (HR+++)	x		
Insulation floor (EPS)			x
Insulation floor (Ecochips)	x	x	
Total investment costs (€)	54.936.316,14	46.238.725,18	48.364.788
Potential reduced energy consumption (m3/year)[14]	1.777.833,18	1.579.419,30	1.515.908,60
Total CO_2 footprint materials (tons)	40.565,33	30.833,65	20.590,28

Table 6.9 Comparison applied measures for each renovation scenario

Although the selected renovation measures differ between the various scenarios, the results related to costs, reduced energy consumption and CO_2 footprint are quite similar for scenario II and III. This can also be seen when comparing average values per house in the figure below.

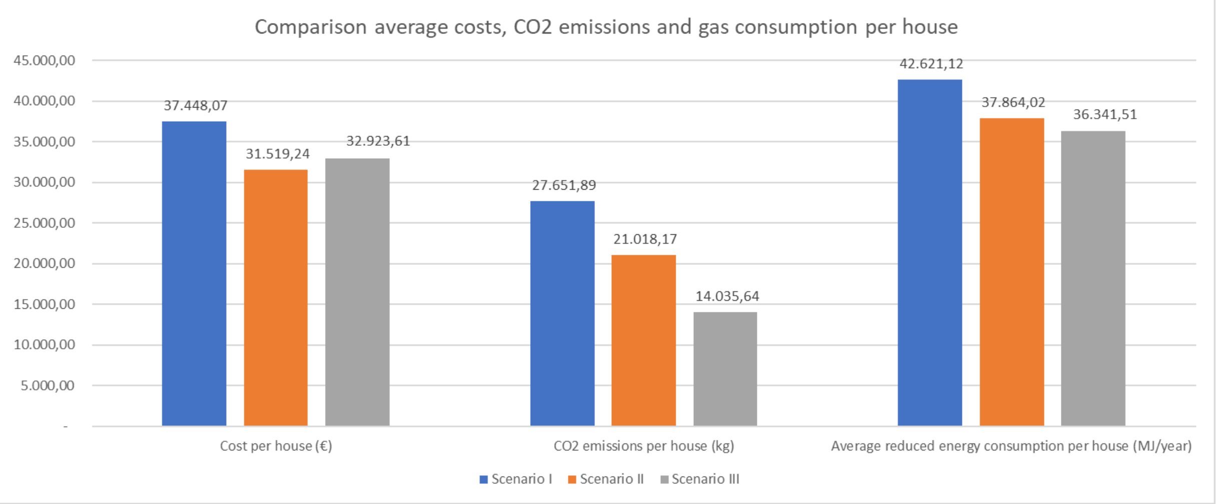


Figure 6.11 Average costs, CO2 footprint and reduced gas consumption per house[15]

[14] As stated in paragraph 5.1.4, the calculated reduced energy, is the energy demand related to heating.

[15] The reduced energy consumption calculated in natural gas was converted to Megajoules to make the graph more readable. The reduced natural gas consumption for each scenario stand for: 1.211,86 m3/year, 1.076,60 m3/year and 1.033,31 m3/year.

As seen in figure 22, scenario I results in a higher needed investment however, the reduced energy is also higher than the other scenarios. Due to the use of triple glazing and materials such as PUR and PIR in this scenario, the CO_2-footprint is significantly higher than scenario III and II. Scenario II has the lowest investment costs per house and has an average CO_2 footprint and potential energy reduction. Scenario III has the lowest CO_2 footprint. Due to the use of insulation materials such as mineral wool, the CO_2 emissions in kg/m2 is rather low. However, this scenario does need more investments per house, while it has the lowest potential energy reduction. All scenarios result in the minimum insulation standards, required for energy neutral buildings. What scenario is the optimal renovation approach depends on the ambitions and goals of the initiator(s). For instance, sustainability or CO_2 emissions is an important factor for the initiator, scenario III would be an interesting approach. Scenario II scores average for all indicators and needs the lowest investment budget. If the demands for energy performance are ambitious and more funds are available, scenario I would be an interesting option.

Example of use tools and models

As stated in paragraph 5.1.4, the final step consists of combining all the outputs, generated by the tools and models, and upscaling this to a higher information level. The GIS-tool determined the building characteristics of the individual houses of the district Kerkdorp Acht. The energy performance predictive models used this output to determine the energy demand and performance of the houses in the entire district. With the use of the optimization tool, the potential energy reduction was calculated for each renovation scenario and related to costs, CO_2 emissions and energy savings. By combining this information of all the individual houses, and categorizing them based on their energy reduction potential, building type and energy performance the houses can be clustered together. In order to demonstrate how the tools and models can be used for identifying opportunities for applying large-scale renovation strategies, a large-scale renovation strategy potential map for each scenario was put together using the GIS-tool. The produced maps are shown Appendix X. As shown in the maps, the potential differs in each scenario. Scenario I has a higher potential for applying a large-scale renovation strategy focused on phase 1 (reducing the energy demand) compared to the other scenarios. This can be explained by the higher potential energy reduction due to the use of the optimal energy performance renovation measures. What can be noted in the provided maps in Appendix X is that most of the detached houses have a rather good energy performance, but still have a large potential for applying renovation measures. This can be explained by the rather high energy consumption. As stated in chapter 3, the actual energy consumption is dependent on both building- and household related characteristics, such as the occupant's behaviour. This shows that, although the energy performance of the building is rather good, the behaviour of the occupant still has a lot of influence on the reduction potential. Even though these aspects are not considered in the proposed optimization tool, they are very important to consider in a large-scale renovation strategy.

The opportunities that emerge from the tools models can be a used to support in the process for deciding on an optimal large-scale renovation strategy. The maps can be used by stakeholders such as governments, companies, housing corporations and energy cooperatives. In this way, stakeholders such as municipalities can more specifically use their communication and marketing to move owner-occupiers to take specific energy-saving measures. For instance, when using the maps provided in Appendix X, one large-scale renovation strategy could be focused on targeting the detached houses with a high potential for phase 1 by using a collective approach for applying passive measures. Like the renovation projects shown in paragraph 4.2.3 using a collective approach can save money due to economies of scale. In addition, it allows to use a collective subsidy application for energy-saving measures.

6.3 Improvements

By using the various tools and models in a test case, the models could be compared to each other. In the previous paragraphs, the results from the GIS-tool, the two-energy performance predictive models and the optimization tool were elaborated. By comparing the outcomes to actual data insight can be given in the accuracy of some of the models. Furthermore, based on the results from test case, improvements can be recommended regarding the usability and functionality for the various models. In this paragraph these recommendations are discussed per tool and model.

GIS-tool

As explained in chapter 5, the GIS tool was developed to gather basic information about the building characteristics, such as type of housing, year of construction and surface area. This information, in combination with other data, is used as the input for the energy performance predictive models and optimization tool. Like a chain is as strong as its weakest switch, outdated, unreliable or inaccurate input makes the outcomes of the models less reliable and usable. As shown in paragraph 6.2.1, the GIS-tool shows some irregularities. This results in a less accurate prediction of some archetypes, especially row houses and semi-detached houses. These differences can be explained due to inaccuracies and incorrect information from the BAG. Although these inaccuracies can be fixed (the BAG is an external dataset), these can be filtered out. For instance, by benchmarking the results with actual registered types of housing based on statistical datasets from municipalities.

Energy performance predictive models

In this study, two bottom-up models were developed in order to predict the energy demand and related energy performance. The results of both models were compared to the measured gas- and electricity consumption data of 2010. Based on this comparison the reliability of both models could be addressed. Improvements can be made in order to improve the reliability and functionality of the models.

As shown in the previous paragraphs, the statistical model can predict the gas demand slightly more accurate compared to the uniform model. The predicted electricity demand is quite similar to the predicted values from the uniform model. Both models have a different approach in predicting the energy consumption. The statistical model uses a multiple linear regression method. A big and clean dataset is needed in order to produce an accurate outcome. The predicted outcome deviated a lot compared to the measured data. The inaccuracies can be explained by a couple of reasons. Firstly, the characteristics of the buildings derived from the GIS tool might be significantly different from actual characteristics (as shown in 6.2.2). Secondly, the actual state of the renovation of buildings has an impact on results and might explain the larger deviation of energy consumption. Thirdly, the regression model does not consider the behaviour of occupants and indoor environment conditions. Studies have shown that the actual occupant's profile plays an important role in consumption (Majcen, 2016; Sunikka-Blank & Galvin, 2012). This aspect may hinder the results. Finally, the test case consisted of a rather small number of observations. A larger test case might result in a more accurate outcome. This regression model could be improved by adding other predictors such as occupant's behaviour. A follow-up study is needed in order to fully explain the deviations from the measured data.

Regarding the uniform model, key figures and reference values are used for estimating the building's energy demand and performance. The predicted electricity demand is comparable to the statistical model. Regarding the gas demand, the uniform model is slightly less accurate. This can be attributed to different causes. Firstly, these key figures are calculated based on average building and household specifications. Benchmark values are given at national level for prototypical dwellings representative of the stock and assuming specific building characteristics, such as dwelling configuration, floor surface, insulation level, heating and ventilation system, etc. However, this model is easier to use and requires less input. For a consistent and reliable result for both energy demand and for data regarding the existing construction a complete, reliable and regularly updated library can be collected from key figures.

Optimization tool

As shown in paragraph 6.2.3 the optimization tool resulted into three different approaches in order to renovate the existing housing stock of Kerkdorp Acht. In order to provide more information regarding the opportunities for applying an optimal large-scale renovation strategy, a map was created for each scenario. This map shows which houses can be clustered together to develop a large-scale renovation strategy, related to opportunities, for instance realizing an energy neutral residential district. Although the model did not select the 'optimal' large-scale renovation strategy, it does provide crucial information for the decision-making process to choose an optimal strategy. This can information can be used by stakeholders such as housing corporations or municipalities to decide on a certain large-scale renovation strategy for a cluster of houses or residential district. Although this information can be of use, there are a couple of improvements which can be made that can make the information more reliable and useful. The recommended improvements are elaborated in the sections below.

Integrating social-economical and household characteristics
Although the information provided by the various tools and models can be of use for stakeholders such as housing corporations and municipalities, more insight can be given if certain aspects are added. First of all, the generated output of the tools and models focus on the building characteristics. Even though housing characteristics are used in the statistical model, this was merely done to provide a more accurate prediction of the energy performance. These household characteristics are not considered when determining the potential for large-scale renovation strategies in the optimization tool. However, as explained in chapter 3 and 4, household characteristics have to be considered in renovations since they influence the energy demand. Aspects such as the household composition, age and consumption behaviour are related to the actual energy consumption. As stated in chapter 3, only focusing on the building characteristics can result in an over- and underprediction of the energy demand, resulting in misleading energy reduction predictions of applied renovation strategies. In addition, these aspects are related to comfort requirements as well. Renovations can have a (negative) influence on the comfort settings in a building (Konstantinou, 2014). Although it is difficult to quantify aspects such as comfort, or the direct effect of household characteristics on renovation strategies, it is still necessary in order to select an optimal renovation strategy. Although there are some studies conducted on quantifying these aspects, nevertheless a follow-up study is needed in order to integrate these aspects into a model.

In addition, social-economical characteristics such as the type of ownership are important aspects of large-scale renovations. Depending on the type of ownership (owner-occupied, social rental or private rentals), different barriers and bottlenecks apply in renovation projects. As explained in chapter 4, a large-scale renovation approach is often not interesting for owner-occupied houses. In practice it is often hard to convince a group of owner-occupiers to apply a large-scale renovation furthermore, house-owners often require and demand customization. For houses owned by a housing corporation, a large-scale renovation strategy is more suitable however, consent is needed of 70% of the tenants (Kramer, 2016). Adding the type of ownership can be especially interesting for determining the potential for applying a large-scale renovation strategy. By indicating private or public owned property, more insight can be given for stakeholders such as energy cooperatives or municipalities in the potential for applying a certain large-scale renovation strategy.

Integrating active measures
The current optimization tool only focuses on passive measures. Integrating active measures into the tool, such as the possibilities for applying solar PV, heat pumps and ventilation can give more insight into the optimal strategy. As described in chapter 4, active measures are needed in order to produce and distribute the remaining energy needed after a passive measure are applied. Active measures are key in realizing an energy neutral building stock since they can provide the needed energy for buildings. Based on the surface, angle, and orientation of the roof in combination with the amount of solar radiation, the potential for solar PV can be analysed. This can be incorporated in the developed GIS-tool.

In order to integrate active measures such as heat pumps and other renewable options for producing the needed energy for heating and hot water use, a follow-up study is needed. For an effective use of heat pumps or district heating, a low energy demand is needed (Ecofys, 2016b). However, the possibilities for applying these depend on many building- and spatial related characteristics. Factors such as the type of radiators present in a building for heating, or the possible heat sources present in the direct environment needed for a heat pump or district heating. These measures have spatial consequences as well, both as a result of the scope and location of the techniques, as the needed storage and transport of energy (Ecofys, 2016b). Providing this information can be of great value when determining an optimal renovation strategy for a district. For instance, when a municipality is looking for the optimal location for developing district heating. Furthermore, by precisely splitting out the potential for passive and/or active measures one can do more. For example, indicating the potential for the first set of measures (addressing lighting, ventilation heat recovery, solar collectors or solar PV). These measures can be recovered relatively quickly. Indicating the potential for a more expensive or less known measure, such as a heat pump can be indicated with a certain threshold. By giving a (subsidy) incentive at the right 'moment' it can be ensured that more people take these measures, for instance using a collective large-scale renovation approach (Posad, 2016). By adding active measures in combination with the socio-economical characteristics of individual houses on a district level, key information can be generated which can be used by several stakeholders. Stakeholders such as municipalities, housing corporations and energy cooperatives. For instance, by generating maps which link the residual energy demand of individual houses on a district level with possible rest heat, or existing district heating.

Furthermore, based on the type of housing, ownership and energy demand certain districts can be selected where the expansion of a heat network can be a possible solution for realizing an energy neutral residential district (Posad, 2016).

Life-cycle costs analysis

Although an indication is given of the needed investments for applying a certain renovation strategy, more insight into the financial benefits can be indicated with the use of a life-cycle costs (LCC) analysis. An LCC-analysis can give more insight into the costs and benefits of renovation measures, by considering the service lifetime per measure. Some building components have a shorter lifetime than others and need replacement or maintenance more often. Components such as the installations. By including the costs of replacement and maintenance and the economic benefits per renovation measure, an optimum renovation budget can be determined which minimizes the total LCC costs. Based on this optimum renovation budget, certain renovation measures can be selected which maximize the benefits and minimize the costs. By considering this for each renovation measure, an optimal renovation strategy can be determined which integrates the renovation measures with the best LCC. Using an LCC-analysis can give more insight into the financial aspect of a large-scale renovation (Jafari & Valentin, 2017).

6.4 Sub-conclusion

This chapter shows that improvements can be made, with regard to the quality and the operation of the tools and models. The GIS-tool, for instance, shows some irregularities regarding the prediction of row- and semi-detached houses. Since this output is used in the other tools and models, this can affect the reliability of the overall output.

The two energy performance models have different approaches in predicting the energy demand and performance. This can be observed in the results of the case study. Although the statistical model does provide slightly better gas predictions, the predicted values still differ a lot compared to the measured data. This can be explained due to the inaccurate data derived from the GIS-tool and missing values in the aggregated energy data. The prediction of the electricity demand is similar compared to the predictions of the uniform model. For now, the uniform model does seem to be more usable for the proposed model framework. In contrary to the statistical model, the uniform model requires limited data, time and expertise in order to predict the energy demand and performance. Furthermore, the predictions are quite similar compared to the statistical model.

Based on the results it can be stated that the predicted energy demand, and thus energy performance will not be fully accurate. Whether this is bad depends on the question that has to be answered. If the models are used to determine the energy performance and renovation approach for an individual building, then the models won't suffice. If the goal is to quickly analyse multiple districts or a city with regard to the energy performance, then these approaches could work. However, in order to fully understand the reliability of both models, a follow-up study is needed to explain the deviations in predicted and measured data. Testing both models in more cases could provide more insight into the usability of the designed models.

The optimization tool shows key information regarding the effects of different strategies related to costs, energy reductions and CO_2 emissions. By combining the various building related characteristics with the predicted energy performance and energy savings, maps can be produced which can be used to determine the potential for applying a large-scale renovation strategy. This information can be of great use for supporting the decision-making process for stakeholders such as municipalities, housing corporations or energy cooperatives. Improvements can be made in order to make this output even more useful. Providing this model with more information such as socio-economical aspects and adding active measures could improve the outcome. Combining these aspects with the output of the current tools and models can provide significant information for stakeholders such as policymakers, housing corporations and house owners in the process of determining the optimal renovation strategy for individual houses on a district level.

7 CONCLUSION, DISCUSSION AND RECOMMENDATIONS

This chapter provides an answer to the main research question. This is:

How can the large-scale renovation strategy of existing houses be optimized by predicting the energy performance and proposing renovation strategies by using a model, particularly in the Netherlands?

First of all, a conclusion is given for the main research question (§7.1). Subsequently, the research design and results are discussed, as well as the reliability of the results (§7.2). Recommendations are formulated regarding the proposed tools, models and follow-up studies (§7.3).

7.1 Conclusion

The purpose of this thesis was to give insight into how the large-scale renovation strategy can be optimized with the use of a model. This model has to predict the energy performance and propose suitable large-scale renovation strategies. In order to do so, insight was needed in energy performance parameters and large-scale renovation strategies. This was done based on the existing literature, reference projects and expert judgement.

In order to understand how the large-scale renovation strategy can be optimized, insight was needed in the renovation process on a large-scale. As shown with the reference projects, certain large-scale renovation strategies are used for a cluster of houses with the same characteristics. Most of these strategies use key renovation principles, such as reducing the energy demand by applying passive measures. Nonetheless, there is no “one size fits all” optimal large-scale renovation strategy, which can be used to improve the entire existing housing stock. The decision-making process for choosing an optimal large-scale renovation strategy is too dependent on the characteristics of the specific situation. In any decision-making process, whether this is done by a housing corporation, municipality or a single home-owner, there is a wide variety of possible renovation strategies that can be considered and it is not easy to select the optimal one. The decision-process for renovation projects include many bottlenecks such as changes in consumption behaviour, ability to change the appearance, building conditions, type of ownership and energy performance. This selection process of an optimal large-scale renovation strategy can be seen as a trade-off between ambitions and requirements of the relevant actors (e.g. homeowners and housing corporations), the financial investment needed and the benefits obtained from that renovation strategy, constrained by the relevant parameters.

In order to simplify and facilitate this decision-making process for stakeholders like housing corporations or municipalities, a model framework was designed. This model framework is based on the combination of various tools and models and can be seen as a decision-support instrument. The instrument can be used by Witteveen+Bos to assimilate key information of individual buildings and lift this to a larger scale (e.g. district level). In this way, insight can be given for stakeholders like housing corporations or municipalities in the energy performance of houses and the possible large-scale renovation strategies on a district level. The model framework was designed based on an extensive literature review, summarized in chapter 3 and 4, reference projects and expert judgement from both internal (Witteveen+Bos) and external professionals.

The advantage of the proposed model framework is that it can provide a quick analysis of the energy performance and opportunities for applying certain large-scale renovation strategies. With the use of a case study, the tools and models were tested using three possible renovation scenarios’. The case study shows that the potential for applying a large-scale renovation strategy differs, based on the building characteristics, type of housing, energy demand and performance. What is interesting, is that the potential for applying large-scale renovation strategies is rather high, despite the good energy performance of the houses in the district. These results are discussed in the following paragraph.

7.2 Discussion

In this thesis, various tools and models were developed in order to predict the energy performance and propose possible large-scale renovation strategies for individual houses on a district level. In this paragraph, the limitations, results and reliability of the tools and models are discussed and interpreted.

Research design

During the research, certain choices were made regarding the scope of the thesis and developed tools and models. As mentioned in chapter 2, the research approach of this thesis was mainly model-based. This means that the main function and goal of the thesis was to propose a model framework, which can be used as a basis for follow-up studies. Furthermore, the research was mainly focused on analysing the relation between the building characteristics of the existing housing stock (e.g. building type), the energy performance and large-scale renovation strategies. Although aspects such as household and socio-economic characteristics were analysed as well, this was needed in order to understand the total spectrum regarding the energy performance and renovations. The designed tools and models were mainly limited to predicting the potential energy reduction by improving the energy performance using renovation strategies that target the building characteristics. These tools and models were not designed in order to improve the energy performance with the use of certain measures targeting household characteristics, such as energy control systems and behavioural measures. Although some household characteristics were used in the statistical model in the end, this was only done in order to get a more accurate prediction of the energy demand and performance. These characteristics were not used in the other tools. Even though characteristics such as the type of ownership and consumption behaviour should be considered in renovations, it is impossible to integrate all the relevant parameters in the tools and models, timewise. A choice was made to focus on the building related characteristics and renovation strategies that apply in order to improve the energy performance of the existing housing stock.

Results tools and models

In chapter 6 the designed tools and models were used and tested in a case study. First of all, the determined types of housing from the GIS-tool were compared with registered data of the city of Eindhoven. This tool can be very useful for the determination of building types and gathering building-related data. Since there are no open data sources available with building specifications per individual house on a large-scale, the GIS-tool could provide the required data needed for the other tools and models. However, as shown in chapter 6, there are some irregularities in the tool. The GIS-tool does provide an accurate prediction of the types of housing on a city level. However, when using the tool on a single district, some types of housing are over- and underpredicted. Row houses are overpredicted up to 156,50%. Corner- and semi-detached houses are underpredicted with 43,83%. This is caused by inaccurate data derived from the Basic Administration Buildings (BAG). Although this could be 'filtered' out by benchmarking the data with aggregated statistical data, a fully accurate prediction will not be achieved. This is the result of software limitations and the use of external datasets.

These inaccuracies in the derived output from the GIS-tool also explain some of the inaccurate energy demand predictions of the statistical model. Although the statistical does show some significant results and similarities compared to other studies (Guerra Santin et al., 2009; Mastrucci et al., 2014), the predictive power of the model is rather weak. Especially the regression model for prediction the electricity demand shows weak predictors. Predictors such as the type of housing. This could be explained due to the fact that electricity demand is less dependent on the type of housing. As elaborated in chapter 3, and shown by the graphs in Appendix VIII, a large part of the electricity demand is determined by the use of electrical appliances and lighting. This usage is more related to household characteristics. The gas demand regression model has more significant predictors, such as the level of income and surface area. However, predictors such as semi-detached houses and construction periods between 1946 and 1991, were less significant. Compared to the measured data, the predicted gas and electricity values deviated considerably in the case study. On average, more than 60% of the predicted gas and electricity values deviated more than 20% of the measured data. This can be explained due to the inaccurate input with regard to the building types and energy figures derived from the network operators. For now, the uniform model seems more usable. The uniform model is less complex and easier to use compared to the statistical model. However, to fully understand the reliability of both designed models, more insight is needed. A follow-up study could be conducted which uses more test cases and predictors related to parameters such as age and behaviour of the occupant. As shown by the study of D. Majcen, these aspects do have a relation with the energy demand (Majcen, 2016).

The optimization tool gives insight into the potential of applying large-scale renovation strategies on a district scale, related to costs, CO_2 emissions and energy reduction. However, as stated in the previous chapters this tool is limited to the building characteristics. Household- and socio-economic characteristics such as the type of ownership, consumption behaviour and comfort requirements are not considered. As stated in chapter 3 and 4, these characteristics should be considered when determining the energy performance or optimal large-scale renovation strategy in practice. This can also explain why the houses in the case study have a high potential for energy reduction, despite the good energy performance. This can be explained by the consumption behaviour of the occupants. These characteristics, like the various types of ownership and household compositions, have an influence on the decision-making process for an optimal large-scale renovation strategy. Despite the fact that these characteristics are important and interrelated, the focus of the thesis was to set a baseline for a model which can be used to build upon. Identifying the type of ownership or household composition is relevant in determining the energy performance or large-scale renovating strategy. Nevertheless, without knowing the details of the related buildings in a district there is no use of this information. On top of that, as shown in chapter 4, most of the renovation measures are related to improving the building components. These related household- and socio-economic characteristics can be analysed and integrated into the tools and models in a follow-up study.

7.3 Recommendations

With the use of a case study the reliability and functionality of the tools and models could be analysed. Based on the results a couple of recommendations can be listed.

As stated before, there is no 'general' optimal large-scale renovation strategy which can be applied to the entire housings stock. The building characteristics of the existing housing stock are too heterogeneous in order to implement a universal large-scale renovation strategy. In addition, the goals, motivators and requirements with regard to renovating the existing housing stock differ per situation. Nevertheless, these various aspects should be considered in the renovation process, in order to select an optimal large-scale renovation strategy. The designed model framework could provide useful information for stakeholders such as housing corporations, energy cooperatives and municipalities to support this decision-making process. For instance, deciding which cluster of houses to target first and how to improve the energy performance.

Although the presented information can be of use to these stakeholders, the proposed model framework is limited to building characteristics. In practice, there are various types of ownership, household compositions and constellations of actors and initiators present and relevant in large-scale renovations. These aspects are related to the energy performance and have to be considered in large-scale renovation projects. Integrating these household and socio-economic characteristics into the model framework could provide more insight into the possibilities for applying a large-scale renovation strategy. In addition, adding active measures into the optimization tool can give more insight into the optimal large-scale renovation strategy. As stated in chapter 4, active measures such as solar PV, heat pumps and district heating are key in realizing an energy neutral housing stock. On top of that, using a life-cycle costs analysis in the model framework can provide a different financial overview. This can be used to determine an optimal renovation budget. Other aspects, such as benchmarking the results of the GIS-tool with registered data and testing the tools and models in multiple cases are important as well. This can result in a better understanding of the reliability of the designed tools and models.

Although socio-economic and household characteristics were briefly discussed, more insight is needed in these characteristics to integrate them in the proposed model framework. A follow-up study could be conducted in order to fully understand the relation and the specific influence characteristics such as the type of ownership, household composition and age on the decision-making process for an optimal (large-scale) renovation strategy. On top of that, more insight is needed in the optimal renovation strategy with regard to active measures and the needed thermal performance of a house to do so. This information is needed in order to integrate active measures into the model framework.

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I RESEARCH FRAMEWORK AND CONSULTED EXPERTS

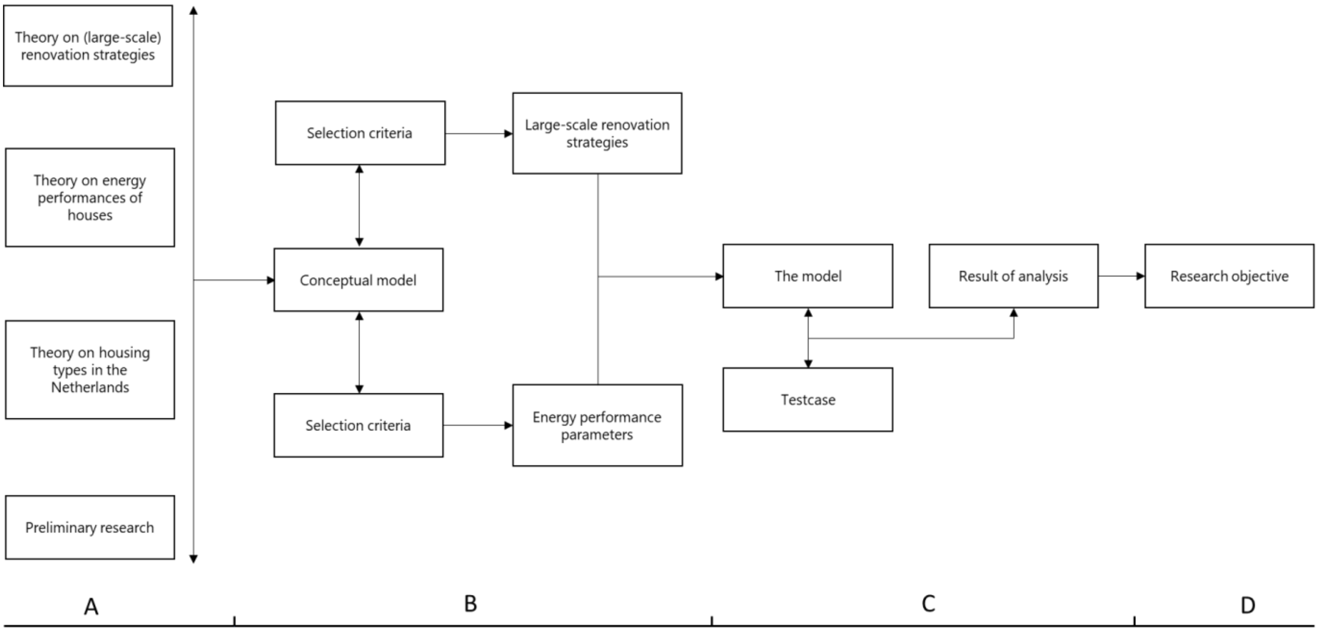


Figure I.1 Research framework

As seen in the figure above section A will provide the theoretical background, in section B this theory will be analysed. Based on the results from section B the model will formed, tested and assessed (section C). The results of this assessment processed into the conclusion (section D).

Name and function expert	**Role expert**	**Organization**
S. Hartwig (co-founder the Efficiator)	Insight in the parameters relevant in renovation projects	The Efficiator
M. Ouwens (head realization large-scale maintenance and renovations)	Insight in the general decision-making process for large-scale renovations	ERA Contour
A. Assad (concept coordinator)	Insight in preconditions existing housing stock	ERA Contour
J. van de Wetering (project engineer building physics)	Insight in preconditions existing housing stock	Witteveen+Bos
J. Slobbe (project engineer energy strategies)	Insight in the general decision-making process for large-scale renovations	Witteveen+Bos
R. Hotchandani (project engineer building physics)	Insight in preconditions existing housing stock and possible modelling techniques	Witteveen+Bos
R. Pelgrum (head building management)	Insight in the parameters relevant in renovation projects	Witteveen+Bos

Table I.1 Consulted experts

II CALCULATION METHODS ENERGY PERFORMANCE INDICATORS

Calculation framework European Energy Performance of Buildings Directive

In this section the calculation framework as stated in the European Energy Performance of Buildings Directive (EPBD) is elaborated. Member states have to develop their calculation methods for energy performance indicators based on this framework (Publicatieblad van de Europese Unie, 2010).

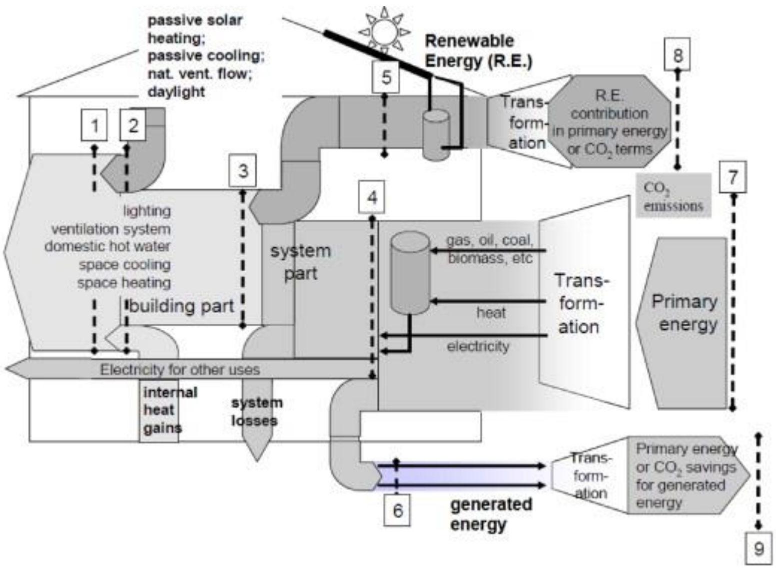
The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs. The methodology shall be laid down taking into consideration at least the following aspects:

- the following actual thermal characteristics of the building including its internal partitions:
    - thermal capacity;
    - insulation;
    - passive heating;
    - cooling elements;
    - thermal bridges.
- heating installation and hot water supply, including their insulation characteristics;
- air-conditioning installations;
- natural and mechanical ventilation which may include air-tightness;
- built-in lighting installation (mainly in the non-residential sector);
- the design, positioning and orientation of the building, including outdoor climate;
- passive solar systems and solar protection;
- indoor climatic conditions, including the designed indoor climate;
- internal load (Publicatieblad van de Europese Unie, 2010).

The following positive influences of the following aspects shall, where relevant in the calculation, be considered:

- local solar exposure conditions, active solar systems and other heating and electricity systems based on energy from renewable sources;
- electricity produced by cogeneration;
- district or block heating and cooling systems;
- natural lighting (Publicatieblad van de Europese Unie, 2010).

Since the member states developed very different approaches and methodologies, standards were established regarding a methodology to calculate the EPB in 2004. These include the following: EN 15217 (energy performance of buildings – ways of expressing the energy performance of buildings and energy certification); EN15603 (the energy-efficiency of buildings – overall energy use and the definition of the energy rating); EN ISO 13790 (energy performance of buildings – calculating the energy used for heating and cooling)(D. Majcen et al., 2013). The CEN standard umbrella document NPR-CEN-ISO/TR 52000-2:2017 (previously, CEN/TR 15615:2008) lists the relevant European standards for the implementation of the EPBD and provides an outline of the calculation procedure for assessing the energy performance of buildings (Publicatieblad van de Europese Unie, 2010).. The schematic illustration of the calculation scheme according to the document is given in figure III.1. The illustration shows the various parameters involved in the calculation (Fokaides, Maxoulis, Panayiotou, Neophytou, & Kalogirou, 2011).



Legend:

1: Heating + cooling needs	4: Delivered energy	7: Primary energy (building)
2: Natural energy gains	5: Renewable energy	8: Primary energy (on site)
3: Buildings energy needs	6: Produced energy	9: Primary energy savings

Figure II.1 Schematic overview of the energy performance calculation (Fokaides et al., 2011)

Calculation method Energy label

In order to determine the energy label, the calculation is based on fixed dimensions of reference homes, which differ per construction period and per type of dwelling. Adjusting these attribute values affects the energy label class (Rijksdienst voor Ondernemend Nederland, 2017c). For houses, all homeowners receive a provisional energy label class, based on already available housing characteristic values. These values are based on information from the land registry and Woononderzoek Nederland (WoON), a research focused on aspects such as the composition of households, the building and the living environment (Gaalen & Staal-Guijt, 2014a; Rijksoverheid, n.d.[3]). This is the provisional energy label. The homeowner then has the possibility to adjust these attribute values in a web application. A recognized expert independently and remotely checks the plausibility of the submitted evidence by the homeowner. By choosing a recognized expert, the home owner gives permission to register the energy label after approval (Gaalen & Staal-Guijt, 2014a; Rijksdienst voor Ondernemend Nederland, 2017c).

The definite energy label is determined with a limited amount of general building characteristics and energetic characteristics. In table II.1 these parameters are shown. The other input parameters are automatically derived from these house characteristics within the energy label. Aspects such as behaviour and electrical appliances other than lighting, heat pumps or solar PV are not considered. Standard housing types and dimensions are included in the calculation method. These dimensions are based on the most common situations in Dutch houses and give a good impression of Dutch houses. The big advantage of working with standard houses is that it is not necessary for the energy label applicant to measure the whole building. The spread in housing sizes and shapes in the Netherlands is not very large and a classification in house type (detached, semi-detached, corner house etc.) and construction year period is sufficient to reflect differences between homes. Starting point for the housing types and geometric parameters of the houses is the publication '*Voorbeeldwoningen 2011 bestaande bouw*', or Example housing types 2011 existing buildings in English (Gaalen & Staal-Guijt, 2014a; 2014b).

Within the energy label method, the housing types (detached, terraced house, etc.) are further subdivided into ten different construction year classes. There are important starting points for the energy label for these building year classes. As an example, a pre-war building in the original situation has a very different level of insulation than a house from 1990. This difference is considered in the energy label method. A house without after-isolation from 1938 therefore has a poorer insulation value than a house without post-insulation from 1980 (Nederland, 2017). The house characteristics are the data to determine the definitive energy label: the type of dwelling, dwelling subtype, year of construction, after insulation facade / floor / roof, type of glazing living areas / sleeping quarters, type of heating system, type of tap water system, type of ventilation system, presence of solar water heater, number of m^2

PV. Based on the determined input, as shown in the table II.3. the definitive energy label can be calculated. This is derived from the Energy Label Number (ELG). The ELG value of a home is calculated using the NEN 7120 method (Gaalen & Staal-Guijt, 2014b). The ELG value is calculated as following:

$$ELG = 7 \times EI + 2$$

In this formula the EI stands for the energy index. The EI is calculated based on the selected input from table II.3 The definite energy label is then derived from the ELG value as shown in the table below (Gaalen & Staal-Guijt, 2014b).

ELG	Label class
<10,6	A
10,6 - 11,8	B
11,8 -14,6	C
14,6 - 16,7	D
16,7 - 18,8	E
18,8 - 20,9	F
> 20,9	G

Table II.1 ELG and related energy label (Gaalen & Staal-Guijt, 2014b)

Calculation method Energy Index

The EI is determined by calculating the total theoretical primary energy usage of a building and subtracting this by the standardized energy usage of a reference building as shown in the formula below (Berben, 2014).

$$EI = 0{,}84 \times \frac{Qtotal}{c1 \times Asurface + c2 \times Aloss + c3}$$

In the table below the parameters of the formula are explained.

Parameter	Definition
$Qtotal$	Total theoretical energy demand of a building
$c1$	Standardized energy consumption per m^2 user surface (244 MJ/m^2)
$Asurface$	User surface of the building (m^2)
$c2$	Standardized transmission loss (87 MJ/m^2)
$Aloss$	Transmission loss surface (m^2)
$c3$	A constant contribution to the reference energy use of existing buildings (5844 MJ)

Table II.2 Definition formula EI (Berben, 2014; Gaalen & Staal-Guijt, 2014a; 2014b)

The total theoretical energy demand is calculated by summing up the primary energy required for space heating, water heating, auxiliary electricity (pumps and ventilators) and lighting, and subtracting energy production from photovoltaic (PV) cells and cogeneration. The EI is then corrected for the floor area of the dwelling and the corresponding heat transmission areas (Majcen, 2016).

Building characteristics		
Parameter	*Input/choices*	*Value*
Housing type	Detached house	
	Semi-detached	
	Terraced	
	Apartments (single layer)	
	Apartments (2 or more layers)	
Building year	till 1945	
	1946 - 1964	
	1965 - 1974	
	1975 - 1982	
	1983 - 1987	
	1988 - 1991	
	1992 - 1999	
	2000 - 2005	
	2006 - 2013	
	2014 - present	
Floor area	Ranges per housing type and building year	m^2
Energetic characteristics		
Parameter	*Input/choices*	*Value*
Glazing living space	single glazing	5,1 W/m^2
	double glazing	2,9 W/m^2
	HR-glazing	1,8 W/m^2
	Triple HR-glazing	1,4 W/m^2
Glazing sleeping room	single glazing	5,1 W/m^2
	double glazing	2,9 W/m^2
	HR-glazing	1,8 W/m^2
	Triple HR-glazing	1,4 W/m^2
Insulation façade	till 1945	Original R_c 0,19 Improved insulation R_c 0,69 Insulated extremely R_c 3,5
	1946 - 1964	Original R_c 0,35 Improved insulation R_c 0,85 Insulated extremely R_c 3,5
	1965 - 1974	Original R_c 0,43 Improved insulation R_c 1,3 Insulated extremely R_c 3,5
	1975 - 1982	Original R_c 1,3 Improved insulation R_c 2,3 Insulated extremely R_c 3,5
	1983 - 1987	Original R_c 1,3 Improved insulation R_c 2,3 Insulated extremely R_c 3,5
	1988 - 1991	Original R_c 2,5 Insulated extremely R_c 3,5
	1992 - 1999	Original R_c 2,5 Insulated extremely R_c 3,5
	2000 - 2005	Original R_c 2,5

		Insulated extremely R_c 3,5
	2006 - 2013	Original R_c 2,5 Insulated extremely R_c 3,5
	2014 - present	Original R_c 3,5
Insulation roof	till 1945	Original R_c 0,22 Improved insulation R_c 0,72 Insulated extremely R_c 3,5
	1946 - 1964	Original R_c 0,35 Improved insulation R_c 0,85 Insulated extremely R_c 3,5
	1965 - 1974	Original R_c 0,86 Improved insulation R_c 2,3 Insulated extremely R_c 3,5
	1975 - 1982	Original R_c 1,3 Improved insulation R_c 2,5 Insulated extremely R_c 3,5
	1983 - 1987	Original R_c 1,3 Improved insulation R_c 2,5 Insulated extremely R_c 3,5
	1988 - 1991	Original R_c 2 Improved insulation R_c 2,5 Insulated extremely R_c 3,5
	1992 - 1999	Original R_c 2,5 Insulated extremely R_c 3,5
	2000 - 2005	Original R_c 2,5 Insulated extremely R_c 3,5
	2006 - 2013	Original R_c 2,5 Insulated extremely R_c 3,5
	2014 - present	Original R_c 3,5
Insulation floor	till 1945	Original R_c 0,15 Improved insulation R_c 0,65 Insulated extremely R_c 3,5
	1946 - 1964	Original R_c 0,33 Improved insulation R_c 0,83 Insulated extremely R_c 3,5
	1965 - 1974	Original R_c 0,17 Improved insulation R_c 1,3 Insulated extremely R_c 3,5
	1975 - 1982	Original R_c 0,52 Improved insulation R_c 1,3 Insulated extremely R_c 3,5
	1983 - 1987	Original R_c 1,3 Improved insulation R_c 2,5 Insulated extremely R_c 3,5
	1988 - 1991	Original R_c 1,3 Improved insulation R_c 2,5 Insulated extremely R_c 3,5
	1992 - 1999	Original R_c 2,5 Insulated extremely R_c 3,5
	2000 - 2005	Original R_c 2,5 Insulated extremely R_c 3,5
	2006 - 2013	Original R_c 2,5

		Insulated extremely R_c 3,5
	2014 - present	Original R_c 3,5
Heater	Individual boiler, installation year <1988	
	Individual boiler, installation year ≥1988	
	Gas stove	
	Heat pump	
	District heating	
	Collective boiler, installation year <1988	
	Collective boiler, installation year ≥1988	
Tap water boiler	Separate tap water boiler (yes/no)	yes, (electrical) boiler
Ventilation system	Natural ventilation Mechanical ventilation Balanced ventilation	
Sustainable energy	Solar boiler	m^2
	Solar PV	m^2

Table II.3 Input parameters definitive energy label (Gaalen & Staal-Guijt, 2014b)

Electricity consumption of household appliances is not calculated in the EI, this also accounts for the gas consumption from cooking. Upon registration of the EI by the energy consultant, a definitive energy label is automatically generated. The relation between the energy label, EI and total theoretical energy consumption is shown in table II.4.

Energy performance indicator (energy label)	**Energy-Index**	**Total theoretical energy consumption (KWh/m²/year)**
A	≤ 1,20	138,48
B	1,21 - 1,40	162,08
C	1,41 - 1,80	174,27
D	1,81 - 2,10	195,60
E	2,11 - 2,40	211,55
F	2,41 - 2,70	223,83
G	> 2,70	232,10

Table II.4 Relation energy label, EI and energy consumption for houses (Filippidou, Nieboer, & Visscher, 2016)

III BOTTOM-UP MODELS - MODEL FRAMEWORKS

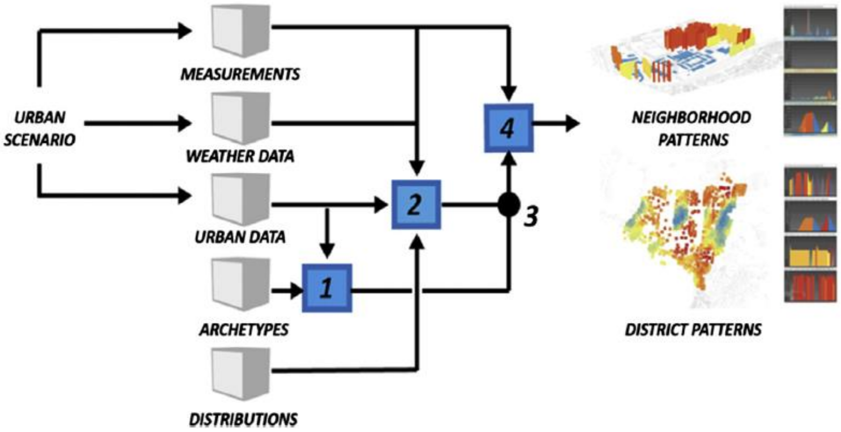


Figure III.1 Framework of the model (Fonseca, et. al, 2015)

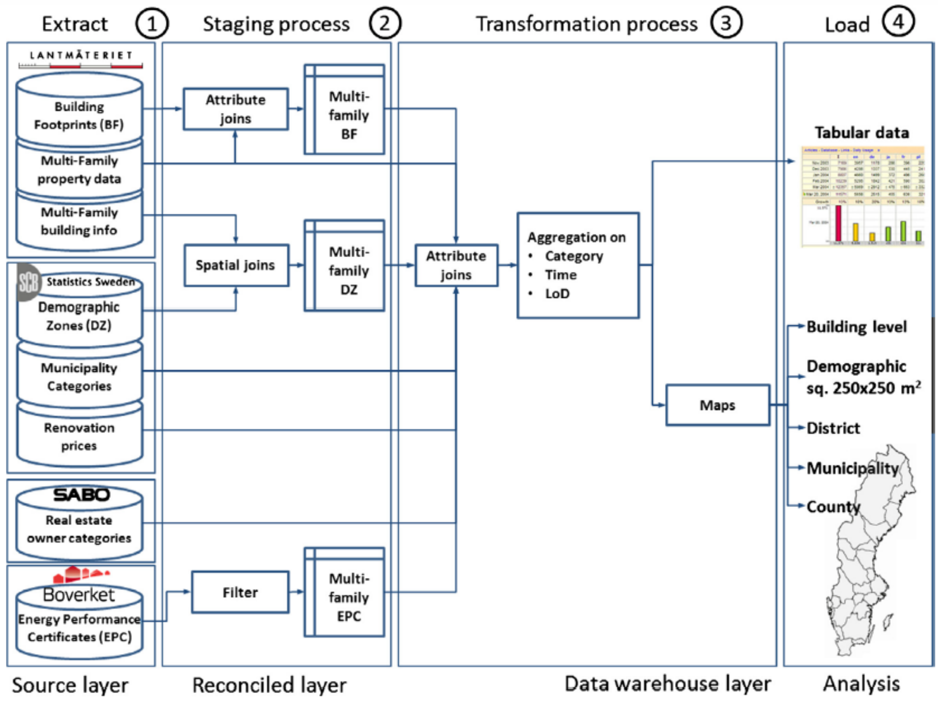


Figure III.2 Framework method Energy atlas (Johansson, et. al, 2017

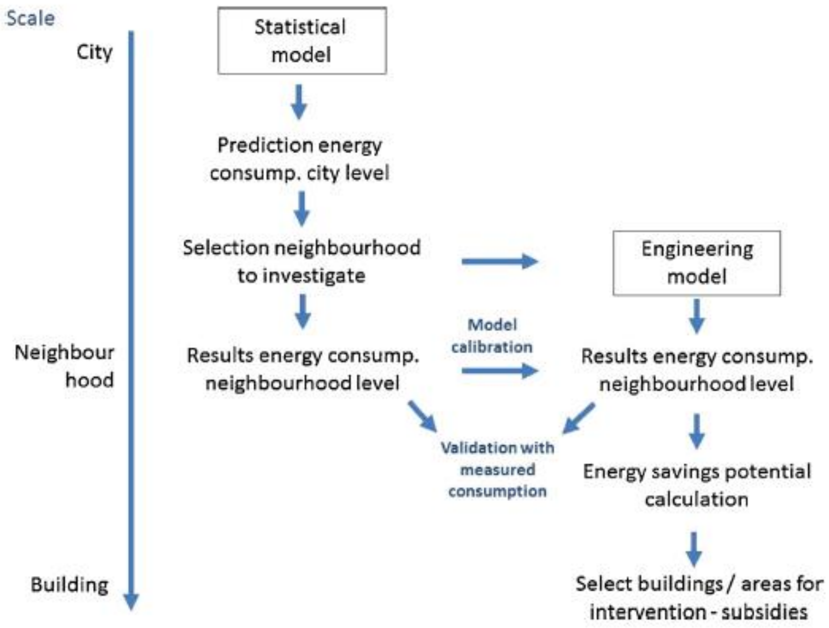


Figure III.3 Model framework bottom-up GIS-tool (Mastrucci et al., 2014; Nouvel et al., 2015)

IV APPLIED MEASURES AND ENERGY PERFORMANCE

The following passive and active measures were derived from the 'Façade Refurbishment Toolbox'. This toolbox, proposed by Thaleia Konstantinou, can be used for supporting the design of residential energy upgrades. In her master thesis, all the possible renovation measures, found in literature and practice, were categorized by the type of intervention and basic renovation principles (Konstantinou, 2014).

Passive measures

The passive measures are used to minimize the energy demand of houses, needed for heating. Most renovation measures are based on applying passive design principles, focusing on the walls, windows, roof and floor.

External and internal walls

The external and internal walls are often the first building component which is addressed in renovation projects. In general, the wall is one of the key components where heat losses occur. A large part of the existing housing stock lacks a sufficient thermal resistance in external and internal walls. For instance, houses built in pre- and post-war periods often have no cavity insulation. In addition, walls have a large surface compared to the floor or roof, and thus a larger transmission loss surface. Renovation measures applied to the walls can be divided into two groups. The first group uses measures that improve the thermal resistance of the building, by applying additional or replacing insulation on the outside, inside or between walls. This reduces the heat flow through walls. The second group includes measures that construct a second 'façade' or wall, which can be applied on the outside of the existing wall (figure IV.1). This creates a thermal buffer (Konstantinou, 2014).

Figure IV.1 Illustration second facade (Konstantinou, 2014)

Window

The windows of a building are often improved at first as well. In general, windows are the components of a building with the lowest thermal resistance. Although the surface area is far less compared to other components, windows accounts for up to 50% of the heat losses through the building envelope. In addition, a major part of the windows in the existing housing stock consist of single and early, uncoated double glazing with poor thermal characteristics (Gustavsen et al., 2011; Rijksdienst voor Ondernemend Nederland, 2017). A lot of energy can be saved by improving the windows. This can be done by applying measures such as the replacement with HR++ glazing or triple glazing. Improving the windows is often done in combination with the improvement of the wall, since both components influence each other with regard to heat transmission. It can be seen as a large tub with water, with one large hole and four small holes. If the small holes are closed, then more water will pour through the large hole. The same effect happens if the large hole is closed. This effect applies to the heat transmission through walls and windows as well. If measured are used on the walls, but not for the windows, then more heat will transmission through the windows (Konstantinou, 2014).

Floor

The floor refers to the building component which is subject to heat losses to the ground or unoccupied spaces, like basements. Although the heat losses are less compared to the windows and walls, more heat is lost in buildings which are subject to the ground (like first-floor apartments) than others (like middle apartments). In this case, the ground has a lower temperature than the occupied space below the middle apartment. In general, there are three types of measures which can be applied. The first measure uses insulation, applied to the top of the floor. However, this does reduce the available space. The second renovation measure creates an insulation slab underneath the floor, for instance in the crawl space. Like the added façade for walls, an additional floor can be added to create a thermal buffer, for instance in basements. This third measure does require a basement (Konstantinou, 2014).

Roof

Like the walls and windows, a major part of the heat is lost through the roof. On average, 25 -30% of the heat is lost through the roof. Roofs are often poorly insulated and on top of that, roofs have a large transmission loss surface. Furthermore, heat is conducted and radiated in all directions, but primarily upwards. Therefore, improving the thermal quality of the roof is an important measure in renovation projects. This can be done in various manners, depending on the roof construction. Additional insulation can be applied to the interior construction of the roof. Insulation can be applied to the external constructions as well. Another measure which is often applied is the insulation of the attic floor (Konstantinou, 2014).

Active measures

In contrary to passive measures, active measures focus on the production and distribution energy. These measures focus on the building installations such as ventilation, lighting and appliances and systems used for domestic hot water use, heating and cooling. Some of these measures can only be applied in large-scale renovation projects, such as the implementation of a heated district or geothermal energy. In the following sections these systems are discussed.

Ventilation

Ventilation is needed in order to provide fresh air and removing polluted air from buildings. As shown in Appendix V, a lot of houses depend on natural ventilation. This implies on the ventilation in a building by opening and closing windows. By using this type of ventilation, the amount and temperature of the air going in and out of a building cannot be regulated precisely. In this process of exchanging air with the inside- and outside of a building, energy is lost. In some cases, this can amount up to half of the energy used in a building. A couple of measures can be applied in buildings to regulate this. Mechanical ventilation systems use fans, ducts, outlets and air terminal devices to supply or extract air. However, in this system the carried energy is still lost. A more advanced system, such as a heat recovery ventilator can reclaim the energy which is carried by air. Using heat exchangers, 60 to 80% of the energy can be recaptured (Konstantinou, 2014).

Lighting and appliances

As shown in paragraph 3.1, lighting and other electrical appliances use up to 15-20% of total energy needed in buildings on average. Although these aspects are often not the main focus in renovation projects, replacing lighting with more energy efficient ones, as well as other household appliances can reduce a lot of energy. However, the use of these appliances and lighting is more related to the consumption behaviour of the occupant. In addition, the use of electrical appliances and type of lighting depends on the preferences of the occupant can be very different in households. Improving energy controls and switches for these appliances could help as well, since consumption patterns determine the major part of the energy consumption for lighting and appliances (Konstantinou, 2014). Since applying these measures has more to do with changing the behaviour of the occupant and due to the fact that it is hard to determine what kind of lighting and appliances are used in households, the aspect 'lighting and appliances' won't be considered in the model.

Heating

Building installations required for heating refer to systems which provide the needed energy for heating a certain space. A wide variety of these systems are used, some are based on fossil energy sources and some are based on renewable energy sources. Furthermore, some systems can only be applied on a large scale, while others focus on single buildings. As shown in Appendix V, most of the heating systems used in the Netherlands are boilers, which use natural gas. This is the most commonly found type of heat generator. Other boiler types use different fuel types, such as biomass, electricity or even oil. The efficiency, in which the energy is transferred int other heating systems has improved greatly in the past decades. However, as shown in chapter 1 and 3, a lot of these systems use fossil fuels. There are a couple of heating system which can be considered in renovation projects, which use renewable sources. The first system uses a solar collector, which captures solar energy to preheat water. This water can then be used to supply hot tap water or heating. Another measure which can be used is a boiler which uses biomass (Ecofys, 2016b; Konstantinou, 2014).

Heat pumps can be used for heating, and hot water supply as well. A heat pump uses electrical energy in order to transfer heat, based on a vapour compressions system. This transferred heat can be extracted from various heat sources, such air, water or ground sources. Heat pumps are categorized by the heat source used: water source heat pumps, ground source heat pumps and air to water heat source pumps. The advantage of these systems is the ability to use low-grade heat in an efficient manner (Ecofys, 2016b).

However, these systems are very costly and can only be implemented if a heat source is available. Another measure which can be applied is a heating system based on geothermal energy. In this system, water is pumped down to an aquiver in the ground where it is stored, heated and transferred back to the surface for heating and hot water supply. However, this kind of system cannot be applied to a single building. This requires a large-scale renovation approach, e.g. multiple blocks or a district. Another large-scale approach is a district- or community heating network. In this system, heat is generated in a central system and distributed to a group of houses. Two types of district heating systems exist, high-temperature and low-temperature systems. A high-temperature (HT) heat network uses water on a high temperature (from 70 ℃) which can be used for simple radiators in houses. A low-temperature (LT) heat network uses water with a temperature of 40-55 ° C which can be used for space heating and/or domestic hot water. However, houses connected to an LT-network need special low-temperature radiators or floor and/or wall heating. This requires a very good thermal and energy performance of the building (Ecofys, 2016b).

Cooling

Besides heating, energy is also used for lowering the temperature in buildings to comfortable setting. As shown in paragraph 3.1, the cooling demand will become a more important aspect the coming years. A couple of active measures can be applied in order to cool buildings. Commonly used measures are air-conditioning systems. Various air-conditioning systems are used, either based on chemical cooling liquids or water-based systems. Other systems are based on heat-cold storage. These systems are often used in combination with supplying heat (Konstantinou, 2014).

Renewable energy production

In order to supply the energy needed for the building installations, renewable energy has to be produced. The most common used systems are photovoltaic (PV) panels. These PV-panels can be applied to single or multiple buildings and transform solar radiation into electricity. This electricity can then be used for building installations such as heat pumps, lighting and other appliances. Photovoltaic systems can reduce electricity demand from electricity network (Konstantinou, 2014). Although there are measures which are applied more often, such as HR++ glazing and solar panels (as seen in the figures in Appendix V), it is hard to determine a specific standard package of measures which have to be applied to reach a certain level. This has to do with the used calculation methods for energy performance indicators such as the Energy label or energy index. In these calculations the total energy demand ($Qtotal$) is one of the key parameters. A lower energy demand, results in a better energy performance. Since there are countless ways to reduce the energy demand (as shown in the previous paragraphs), the renovation strategies are limitless. In addition, the use of renewable energy sources such as solar PV is subtracted from the energy demand. Therefore, more renewable energy production, will result in a lower energy demand and thus a better energy performance (Konstantinou, 2014).

In short, improving the energy performance of house to a certain standard is not a sum of proven techniques. The base situation of a house must be well-founded, aspects such as the orientation, light or solar radiation, insulation and ventilation. Furthermore, matching installations have to be applied for heating, ventilation and hot water to provide an energy balance. A third aspect is that the resident does not renovate exclusively to improve the energy performance, but for better health, comfort, ease of use, appearance and price. In other words: the whole picture has to be right.

To demonstrate this, a fictional detached house was used to elaborate the various means to improve the energy performance. In this case, the house was built in 1996 and has an energy label of C, which was renovated to label A. In figure IV.1, the theoretical energy demand is shown in kWh/m2/year for each renovation approach[16]. In scenario 1, solar PV panels are used in combination with the appliance of HR++ glazing. Although the energy usage is higher in this scenario, the total energy demand is lower due to the renewable energy production. In scenario 2, triple HR+++ glazing is used in combination with applying additional insulation in the walls. The final approach uses measures such as HR++ glazing, better roof and wall insulation. Three different approaches with the almost the same results.

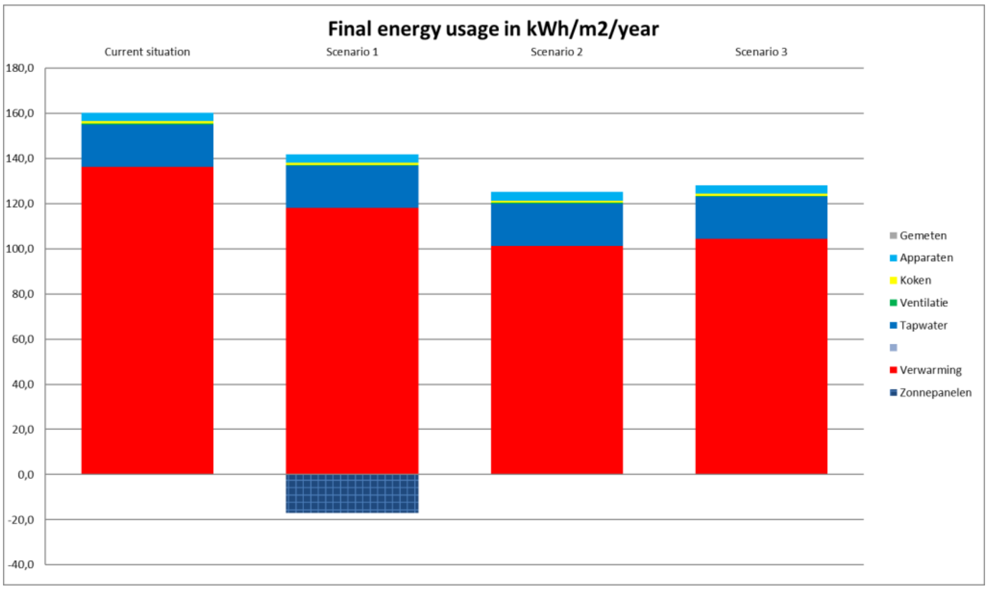


Figure IV.2 Comparison renovation approaches and energy demand

This example shows that, although there are various renovation measures, the outcome can be relatively similar, depending on the building and level of intervention.

[16] The No-regret calculation tool was used to determine this (Energielinq, 2016)

V THE CURRENT RENOVATION STATE

Every year the Netherlands Enterprise Agency carries out a study into the developments regarding the energy savings in the built environment. The latest study resulted in the Energy Saving Built Environment Monitor 2016.
In 2016, the housing stock accounts for more than 7.6 million homes. Approximately 4.36 million (57%) houses belong to owner-occupiers, 2.96 million (39%) are rentals and of the remaining 353,000 homes (4%) are second homes or the owner is unknown. The rental properties (2.96 million) can be divided into 2.2 million houses belonging to housing corporations (29% of the total stock) and 757,917 homes belonging to private renters (10% of total stock). Approximately 14% of the housing stock predates 1931, 14% was constructed between 1931 and 1959, 46% between 1960 and 1990 and 26% since 1991 (figure V.1) (Rijksdienst voor Ondernemend Nederland, 2017a; Rijksoverheid, 2017a).

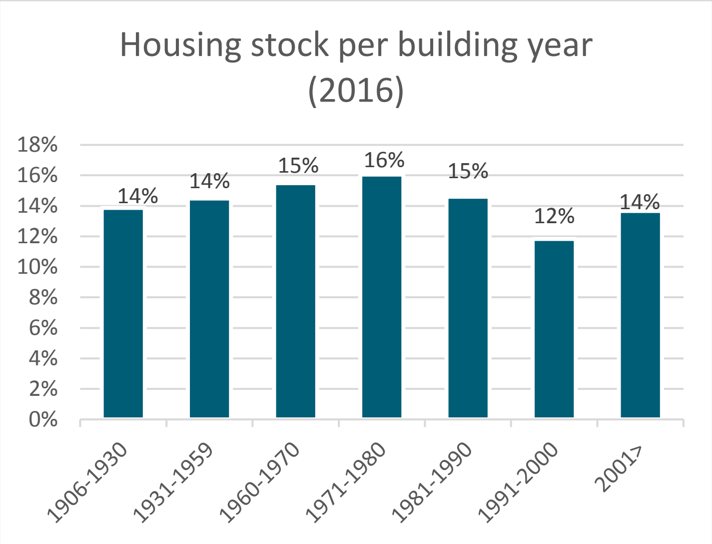


Figure V.1 Housing stock in the Netherlands (Rijksoverheid, 2017a)

Since the introduction of the enforcement and simplification of the energy label since 2015, there is a strong increase in the number of energy label registrations. Especially for owner-occupied properties In 2016, more than 3.2 million homes have an energy label. This is 42% on a housing stock of approximately 7.6 million. Compared to 2015 there is an increase of 4%. The composition by label class as seen in figure 3 gives an important indication of the energy quality of the Dutch housing stock (Rijksdienst voor Ondernemend Nederland, 2017a).

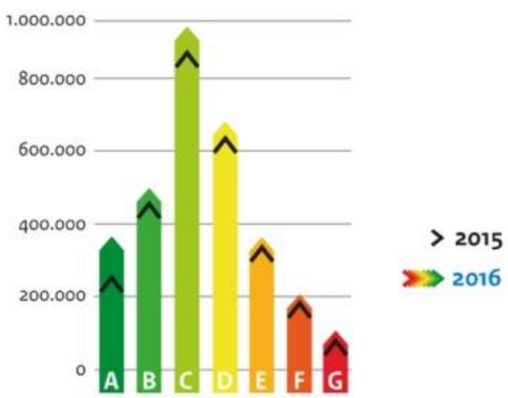


Figure V.2 Distribution energy labels among the housing stock in the Netherlands (Rijksdienst voor Ondernemend Nederland, 2017a)

According to the study, nearly 60% of all houses have an energy label of C or better. For more than 40% of the housing stock action is required to have at least a C label. The share of F and G labels is still on the high side with almost 23%, particularly in the category of private renters. More than three million houses have an energetically poor state (an energy label lower than C). The study shows that these houses have the greatest potential for improvement (Rijksdienst voor Ondernemend Nederland, 2017a). In 2015 Energieonderzoek Centrum Nederland (ECN), or Dutch Energy Research Centre examined what the technical potential is of renovation measures in existing houses. What appears is that there is still a lot of savings possible in the improvement of the building envelope. According to the study, a quarter of the houses still has single glass that can be replaced. In just 70% of homes, double glazing can be replaced with this better insulating glass. In almost half of the houses in the Netherlands additional roof insulation can still be applied and two-thirds of the floors can still be isolated. In addition, in more than 1.5 million houses cavity wall insulation can be applied and in a comparable number of houses wall or façade insulation can be applied on the inside or outside (Rijksdienst voor Ondernemend Nederland, 2017a).

In 2016 the building-related energy saving in housing was higher than in previous years. The growth is present in all three underlying sectors: owner-occupied, social rent and private rent. Energy saving is achieved through both installation and insulation measures and behavioural adjustment on the resident's side. Installation relates to, among other things, the boiler, heat pump, solar panels and solar water heater. Insulation should include glass, roof, floor, wall and cavity wall insulation. Boiler replacement and HR glass are still the most common measures taken in 2016, but especially cavity wall insulation and heat pumps show growth in 2016. In 2016, more than 825,000 homes applied one or more energy-saving measures (Rijksdienst voor Ondernemend Nederland, 2017a).

Most measures have been taken in the owner-occupied sector. Approximately 390,000 homes are connected to a heating network in the Netherlands. In total, these measures have contributed to saving approximately 9,7 Petajoules worth of energy in 2016 (Rijksdienst voor Ondernemend Nederland, 2017a). Not all measures are applied equally often. Installation of an HR boiler and HR glass are the most frequently taken measures in existing houses as shown in the figures below. This can be explained due to the fact that windows are the component of a building with the poorest thermal performance, hence, targeting the windows is one of the key considerations to increase comfort and save energy (Konstantinou, 2014).

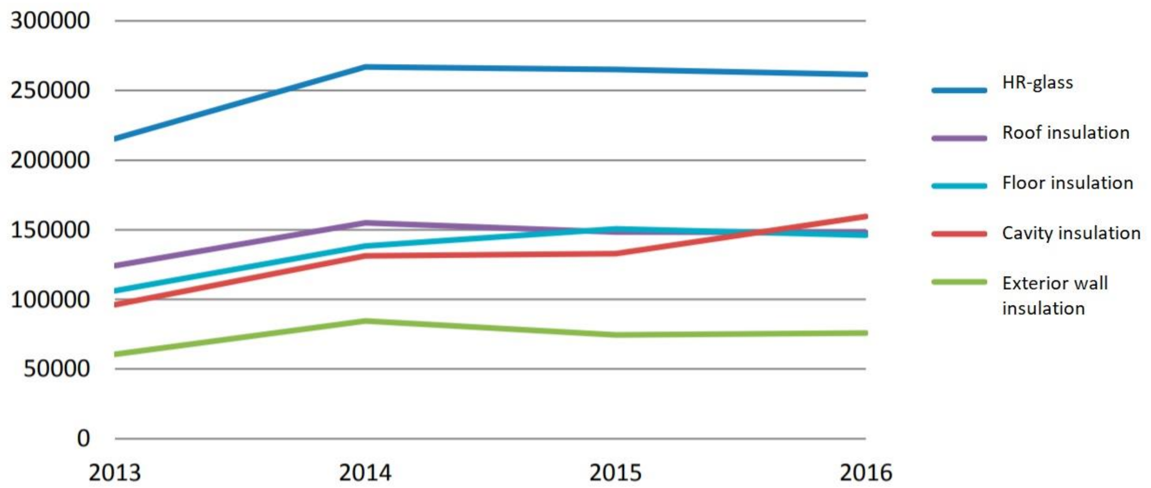


Figure V.3 Number of taken insulation measures (Rijksdienst voor Ondernemend Nederland, 2017a)

When looking at the installations, most of the taken measures are HR-boilers or solar PV-panels. Although the implementation of heat pumps is slightly increasing, HR-boilers are still preferred over (electrical) heat pumps. HR-boilers are popular measures since it immediately results in a reduction of the energy usage. Also, it is a rather simple measure which can be implemented without a lot hindrance, in contrast to heat pumps or solar panels.
Heat pumps have more difficulty dealing with peak demand and therefore function better in homes that cool off slowly on a cold day. In addition, for a properly functioning heat pump good insulation is required. Therefore, before installing a heat pump, investments are needed to improve the envelope of a building. Moreover, an increase in the usage of heat pumps also results in an increase in the electricity demand. The electricity grid is not designed for heating homes with heat pumps on cold winter days, this is what the gas network is meant for. Adaptation of the

electricity grid is necessary in order to replace gas-fired boilers by heat pumps on a large-scale (Rijksdienst voor Ondernemend Nederland, 2017a).

A reason which could explain why solar PV is preferred over heat pumps or solar collectors is the payback period of solar PV panels. Although the PV panels yield the least per m² (a worse yield than thermal panels), this purchase has the quickest payback period, compared to solar collectors or heat pumps, which makes it financially more interesting (Warmtepomp-weetjes, 2018).

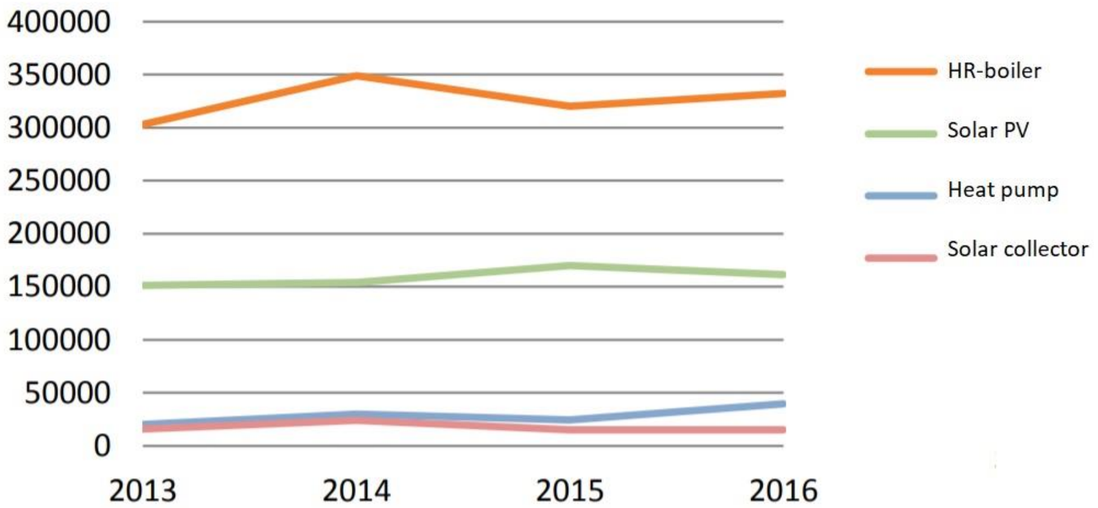


Figure V.4 Number of taken installation measures (Rijksdienst voor Ondernemend Nederland, 2017a)

Although these trends seem positive, a recent study on the renovation rate in the Netherlands shows that the pace is too low to reach the ambitious goals. A linear projection of the developments towards the Energy Index target shows that the goal is not reachable if the renovation rate stays the same (figure V.5).

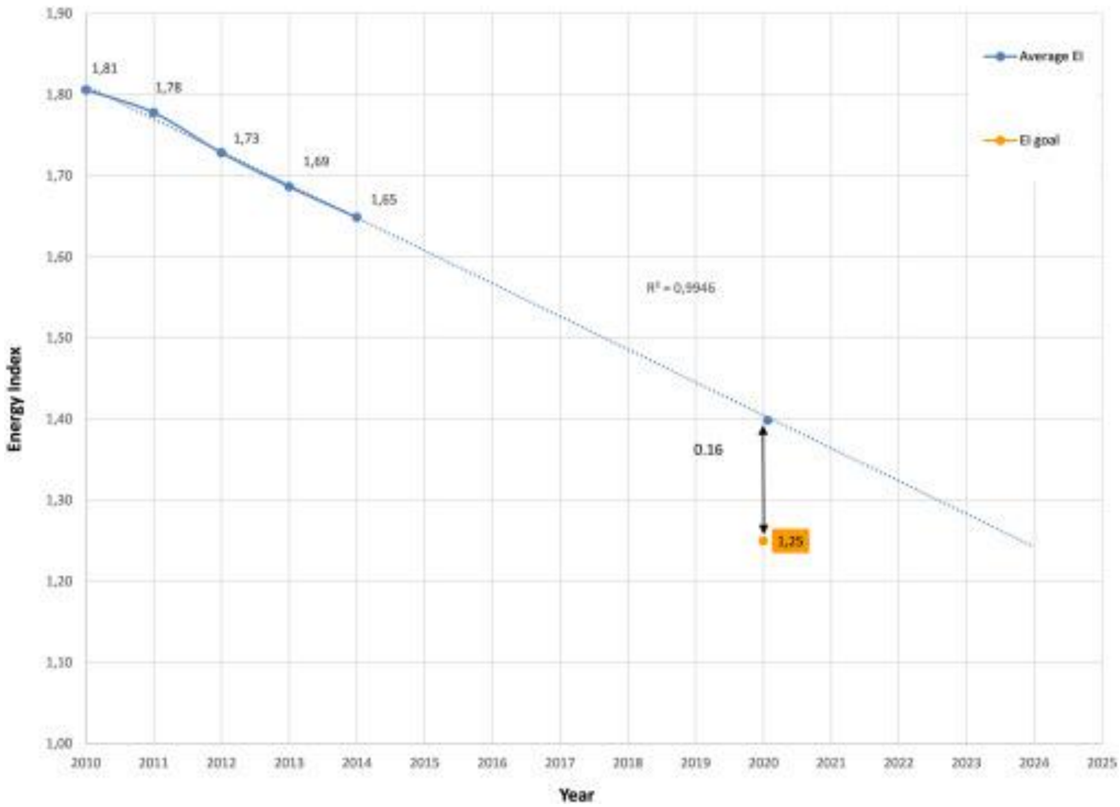


Figure V.5 Development towards the Energy Index target (Filippidou et al., 2017)

VI ASSESSMENT FRAMEWORK

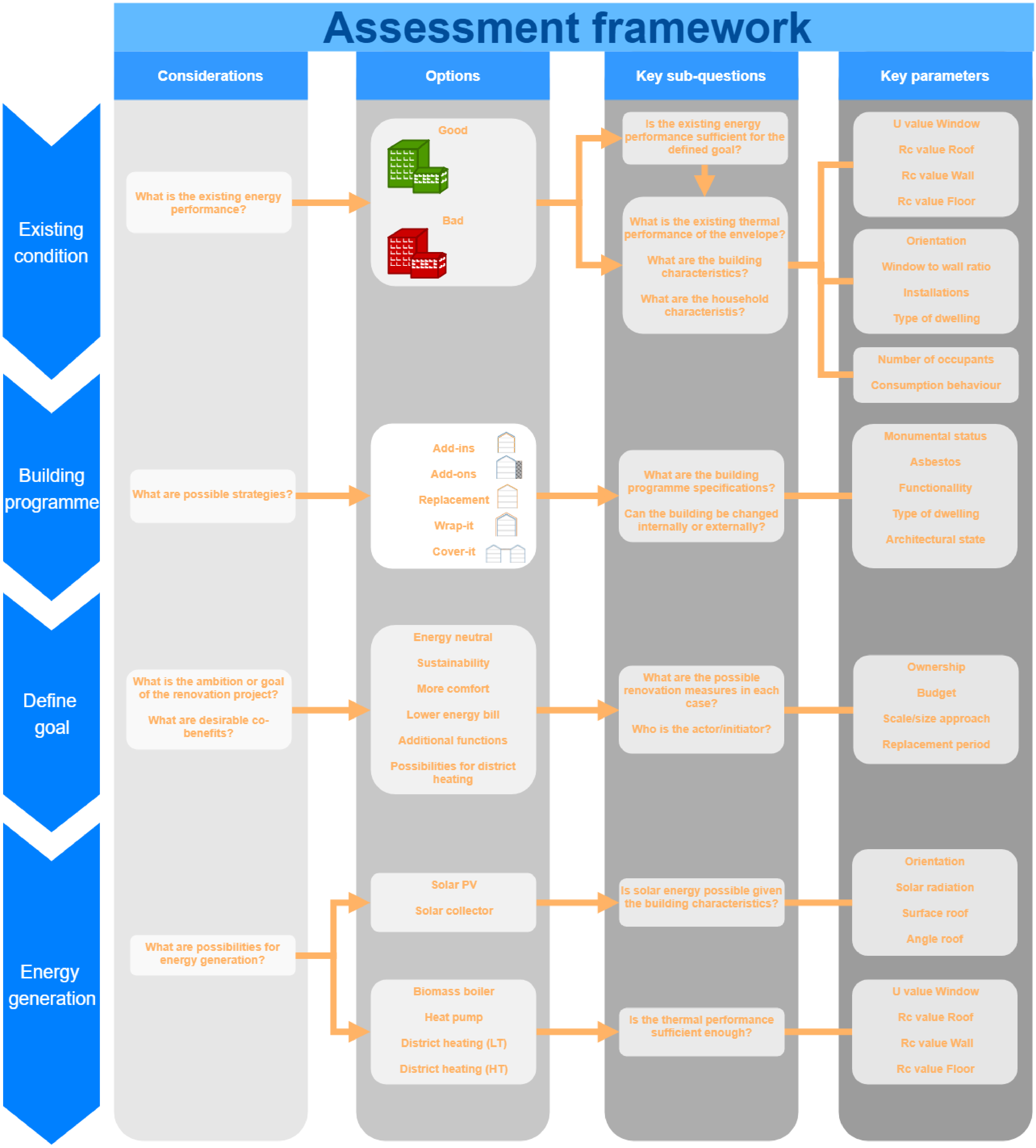


Figure VI.1 Assessment framework

VII MODEL FRAMEWORK

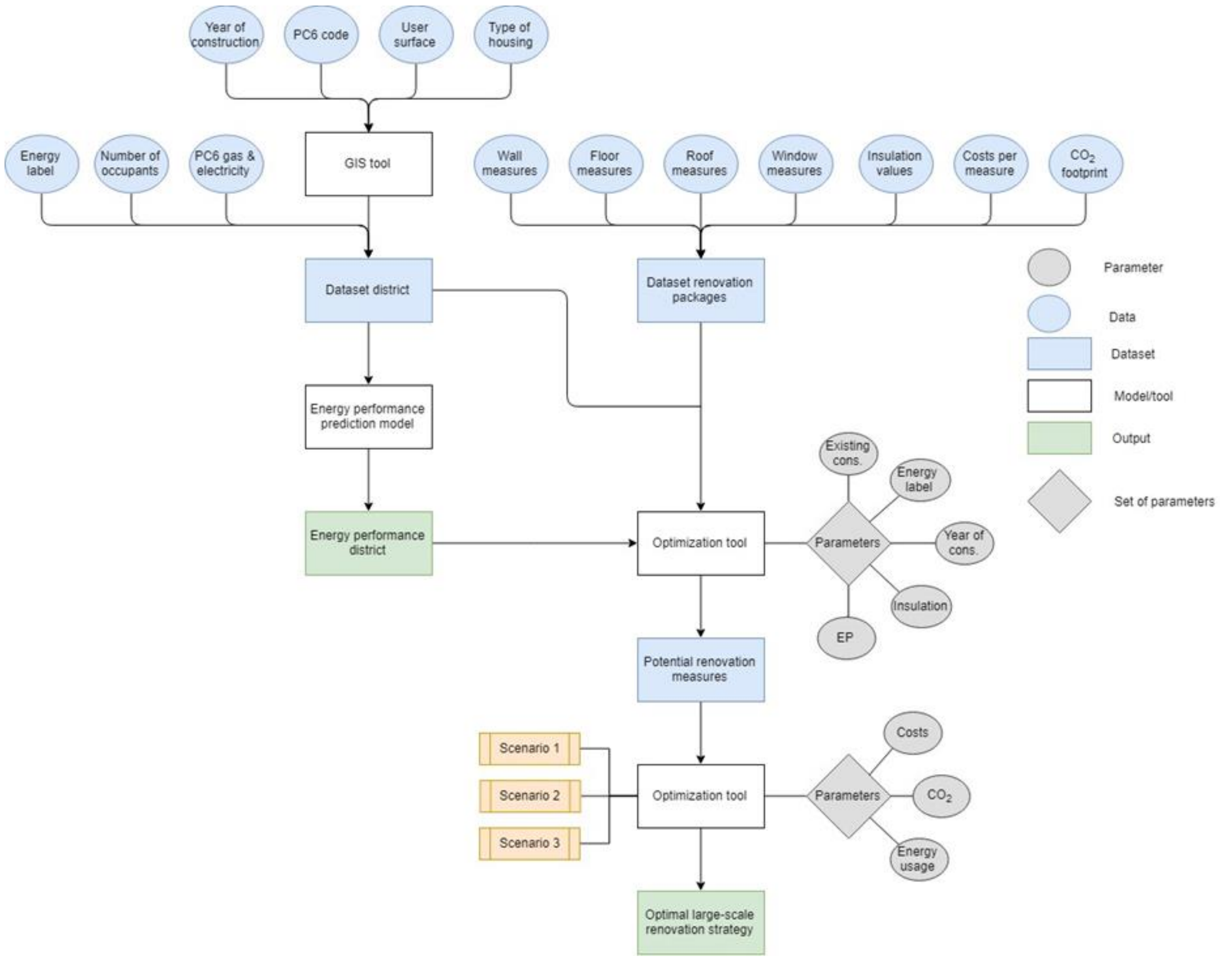


Figure VII.1 Model framework

GIS-tool

When a particular building (building X) contains more than one accommodation or address, the building is expressed as an apartment. When this is not the case, the adjacent buildings will be selected. When there is more than 1 adjacent building, building X can be identified as a row house. When building X has no adjacent buildings it is a detached house. If there is only 1 adjacent building, building Y will be selected. Select that building (building Y) and:

- Building Y has no adjacent property, property X is: semi-detached;
- Building Y also has an adjacent building, building X is a corner house.

The diagram below shows the process of determining the type of housing, as described above.

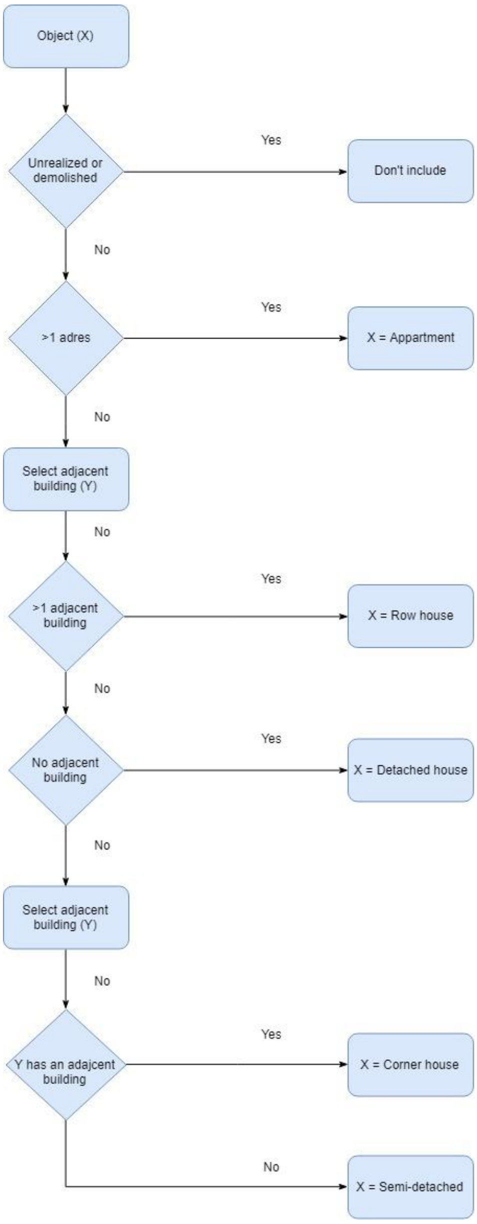


Figure VII.2 Flowchart GIS-tool (Kadaster, 2014)

Housing types			Existing construction						Existing insulation values				
Building type	Construction year	Energy Label	Floor	Wall	Roof	Ventilation	Window living space	Window sleeping room	Rc floor	Rc exterior wall	Rc roof	U window living space	U window sleeping room
Detached	<1945	G	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,15	0,19	0,22	2,9	5,2
Detached	1946-1964	F	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,33	0,35	0,39	2,9	5,2
Detached	1965-1974	E-D	No insulation	Little/outdated insulation	No insulation	Natural	Double glazing	Single glazing	0,17	0,43	0,86	2,9	5,2
Detached	1975-1991	C	Little/outdated insulation	Little/outdated insulation	Little/outdated insulation	Natural	Double glazing	Single glazing	0,52	1,3	1,3	2,9	5,2
Detached	1992-2012	B	Good insulation	Good insulation	Good insulation	Mechanical	HR++ glazing	HR++ glazing	2,5	2,5	2,5	1,8	1,8
Detached	2013-2015	A	Very good insulation	Very good insulation	Very good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	3,5	3,5	1,8	1,8
Detached	>2015	A+/NOM	Super good insulation	Super good insulation	Super good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	4,5	6	1,65	1,65
Semi-detached	<1945	G	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,15	0,19	0,22	2,9	5,2
Semi-detached	1946-1964	F	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,33	0,35	0,39	2,9	5,2
Semi-detached	1965-1974	E-D	No insulation	Little/outdated insulation	No insulation	Natural	Double glazing	Single glazing	0,17	0,43	0,86	2,9	5,2
Semi-detached	1975-1991	C	Little/outdated insulation	Little/outdated insulation	Little/outdated insulation	Natural	Double glazing	Single glazing	0,52	1,3	1,3	2,9	5,2
Semi-detached	1992-2012	B	Good insulation	Good insulation	Good insulation	Mechanical	HR++ glazing	HR++ glazing	2,5	2,5	2,5	1,8	1,8
Semi-detached	2013-2015	A	Very good insulation	Very good insulation	Very good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	3,5	3,5	1,8	1,8
Semi-detached	>2015	A+/NOM	Super good insulation	Super good insulation	Super good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	4,5	6	1,65	1,65
Cornerhouse	<1945	G	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,15	0,19	0,22	2,9	5,2
Cornerhouse	1946-1964	F	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,33	0,35	0,39	2,9	5,2
Cornerhouse	1965-1974	E-D	No insulation	Little/outdated insulation	No insulation	Natural	Double glazing	Single glazing	0,17	0,43	0,86	2,9	5,2
Cornerhouse	1975-1991	C	Little/outdated insulation	Little/outdated insulation	Little/outdated insulation	Natural	HR++ glazing	Double glazing	0,52	1,3	1,3	1,8	2,9
Cornerhouse	1992-2012	B	Good insulation	Good insulation	Good insulation	Mechanical	HR++ glazing	HR++ glazing	2,5	2,5	2,5	1,8	1,8
Cornerhouse	2013-2015	A	Very good insulation	Very good insulation	Very good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	3,5	3,5	1,8	1,8
Cornerhouse	>2015	A+/NOM	Super good insulation	Super good insulation	Super good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	4,5	6	1,65	1,65
Rowhouse	<1945	G-F	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,15	0,19	0,22	2,9	5,2
Rowhouse	1946-1964	E	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,33	0,35	0,39	2,9	5,2
Rowhouse	1965-1974	D	No insulation	Little/outdated insulation	No insulation	Natural	Double glazing	Single glazing	0,17	0,43	0,86	2,9	5,2
Rowhouse	1975-1991	C	Little/outdated insulation	Little/outdated insulation	Little/outdated insulation	Natural	HR++ glazing	Double glazing	0,52	1,3	1,3	1,8	2,9
Rowhouse	1992-2012	B	Good insulation	Good insulation	Good insulation	Mechanical	HR++ glazing	HR++ glazing	2,5	2,5	2,5	1,8	1,8
Rowhouse	2013-2015	A	Very good insulation	Very good insulation	Very good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	3,5	3,5	1,8	1,8
Rowhouse	>2015	A+/NOM	Super good insulation	Super good insulation	Super good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	4,5	6	1,65	1,65
Appartment	<1945	G-F	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,15	0,19	0,22	2,9	5,2
Appartment	1946-1964	E-D	No insulation	No insulation	No insulation	Natural	Double glazing	Single glazing	0,33	0,35	0,39	2,9	5,2
Appartment	1965-1974	E	No insulation	Little/outdated insulation	No insulation	Natural	Double glazing	Single glazing	0,17	0,43	0,86	2,9	5,2
Appartment	1975-1991	D	Little/outdated insulation	Little/outdated insulation	Little/outdated insulation	Natural	HR++ glazing	Double glazing	0,52	1,3	1,3	1,8	2,9
Appartment	1992-2012	C-B	Good insulation	Good insulation	Good insulation	Mechanical	HR++ glazing	HR++ glazing	2,5	2,5	2,5	1,8	1,8
Appartment	2013-2015	A	Very good insulation	Very good insulation	Very good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	3,5	3,5	1,8	1,8
Appartment	>2015	A+/NOM	Super good insulation	Super good insulation	Super good insulation	Mechanical	HR++ glazing	HR++ glazing	3,5	4,5	6	1,65	1,65

Figure VII.3 Reference houses (Archidat Bouwinformatie, 2015; Agentschap NL 2011b; Liebregts, 2011; NEN, 2014; Valk, 2011; pers. comm. van de Wetering, 2018)

Building component	Renovation measure	Options	Insulation value U (W/m2K)	Insulation value Rc (m2/K/W)	Costs multifamily house (€/m2)	Costs single-family house (€/m2)	CO2 (kg/m2)	Precondition
Wall	Cavity insulation	50 mm Expanded polystyrene (EPS)		1,52	12,5	13,36	15,8	Suitable cavity wall with little to no insulation and a minimal width of 50mm.
		50 mm mineral wool (glass wool flakes)		1,47	20	21,38	6,41	Suitable cavity wall with little to no insulation and a minimal width of 50mm.
		50 mm (PUR)		1,85	25	26,73	21,9	Suitable cavity wall with little to no insulation and a minimal width of 50mm.
	Internal insulation	100 mm framework and plasterboard (rock wool)		2,78	82,5	88,19	12,82	Flat and accessible inner façade
		100 mm sandwich panel (EPS)		2,94	90	96,21	31,6	Flat and accessible inner façade
Roof	Pitched roof insulation	109mm renovation roof element against existing roof boarding (EPS)		3,50	40,46	43,25	34,44	Flat and accessible inner roof boarding
		127mm renovation roof element against existing roof boarding (PIR)		5,00	49,26	52,66	55,63	Flat and accessible inner roof boarding
		100mm roof element against existing roof boarding (rock wool)		2,78	44,23	47,28	8,01	Flat and accessible inner roof boarding
	Flat roof insulation	100mm roof element against existing roof boarding (rock wool)		2,78	44,23	47,28	8,01	Flat and accessible inner roof boarding
		110mm single multiplex roof element (PIR)		3,50	46,69	49,91	21,9	Flat and accessible inner roof boarding
Window	Double glazing	Standard double glazing	2,9		126,14	118	18,72	Existing frame is maintained and made suitable for new windows
		HR++	1,2		138,22	129,3	25	Existing frame is maintained and made suitable for new windows
	Triple glazing	HR+++	0,8		183,27	171,44	31,2	Existing frame is maintained and made suitable for new windows
Floor	Insulation under	100 mm PUR		3,70	25	26,73	43,8	Crawl space present and accessible
		100 mm EPS element		2,94	33	35,28	31,6	Crawl space present and accessible
		300 mm Ecochips (EPS)		4,05	23	24,59	94,8	Crawl space present and accessible

Table VII.1Reference values renovation measures (Arcadis, 2017; Archidat Bouwkosten Online, 2018; NIBE, 2015; Woonwijzerwinkel, 2018; pers. comm. van de Wetering, 2018)

Elaboration determination costs and insulation values

The costs were based on the basic methodology distinguished by Arcadis in the report 'Actualisatie investeringskosten maatregelen EPA-maatwerkadvies bestaande woningbouw 2017'. This report includes the updated cost- and insulation figures and the justification of the method used. The cost indicators are differentiated by measure according to the type of housing (single-family house versus multi-family dwelling), by project size (single dwelling versus multiple dwellings / project-based), and moment of execution (standing alone versus during natural moment) and split into labour and material costs. The distinction based on house type is based on the established enveloping surfaces of the example houses and the quantities determined thereby. The existing housing stock can be classified to single-family homes (detached, semi-detached, corner- and row houses) and multi-family houses (apartments). For each section, based on this overview of reference houses with the corresponding surface areas, the average sample house is determined. Based on this sample house, the weighted average costs were determined (Arcadis, 2017).

This dataset was supplemented with cost and insulation values from Archidat. Archidat has an experienced team of architectural specialists and engineers. This team has developed extensive libraries with current building cost data that are tailored to the most common building types and activities. The Building Cost Online databases are continuously fed by the current cost and insulation information and expertise of hundreds of producers and suppliers. Thanks to the unique cooperation between Archidat and these producers and suppliers, they able to provide a comprehensive and comprehensive overview of current target prices and insulation values. The building cost system contains prices and product information of tens of thousands of articles, labour standards, building components and key figures regarding insulation values (Archidat Bouwkosten Online, 2018). The figures derived from both databases were benchmarked with the use of expert judgement.

Elaboration determination CO_2 values

The CO_2 emissions are based on the environmental classifications as stated on the online-database established by NIBE. NIBE is the Dutch Institute for Building Biology and Ecology. This database contains the various CO_2 values per building material, used in the renovation measures (NIBE, 2015). The values shown in table VII.1 are derived from this dataset. The following aspects of the assessed emissions in the products are included:

- extraction and transport of raw materials;
- production and transport of materials and semi-finished products;
- processing of production waste;
- transport to the construction site (standard 50 km);
- losses on the construction site;
- processing of construction waste;
- emissions / leaches during the use phase;
- maintenance and replacements of the product;
- demolition of the product from a building;
- transport to the landfill, recycling or incineration plant;
- processing in the waste phase;
- production and disposal of capital goods.

Not included:

- production of excipients with a mass percentage of less than 1%;
- transport of employees and equipment;
- human labour;
- maintenance in the sense of cleaning / cleaning.
- Work on construction (NIBE, 2015)

Zone	Criterium	Description
Floor	No insulation	At the insulation level 'no' the ground floor is not insulated.
	Little/outdated insulation	In the case of little/outdated insulation, moderate insulation is used in the past (3-5 cm).
	Good insulation	Good insulation is required with insulation material of 8-10 cm thickness.
	Very good insulation	Houses that are very well-insulated have an insulation thickness of 15 cm.
	Super good insulation	Houses that are insulated at this level have an insulation thickness of 17 cm.
Wall	No insulation	At the insulation level 'no' there is no insulation material present in the cavity.
	Little/outdated insulation	At the 'little / outdated insulation level, the cavity is insulated or a (moderate) insulation has been used in the past. The insulation thickness of post-insulated cavity walls is equal to the cavity width (5cm and always fully filled).
	Good insulation	In order to achieve the 'good isolation' level, insulation of the cavity is not sufficient. This requires, for example, an (extra) package of insulation material on the inside or outside or the use of an extra good insulating material (such as PIR).
	Very good insulation	Houses that have been very well insulated have an insulation thickness of 16 cm.
	Super good insulation	Houses that have been insulated at this level have an insulation thickness of 21 cm.
Roof	No insulation	The roof is not insulated at the 'no' insulation level.
	Little/outdated insulation	In the case of little/outdated insulation, moderate insulation is used in the past (3-5 cm).
	Good insulation	Good insulation is required with insulation material of 8-10 cm thickness.
	Very good insulation	Houses that are very well-insulated have an insulation thickness of 17 cm.
	Super good insulation	Houses that are insulated at this level have an insulation thickness of 28 cm.

Figure VII.4 Reference building conditions elaboration (Rijksdienst voor Ondernemend Nederland, n.d.12; pers. comm. Assad, Ouwens, van de Wetering, 2018)

Type of dwelling	Year of construction	UMGO heating demand values (kwh/m2/year)	UMGO electricity demand values (kwh/m2/year)
Detached	<1945	392,52	22,8
Detached	1946-1964	392,52	22,8
Detached	1965-1974	317,67	22,7
Detached	1975-1991	177,35	22,6
Detached	1992-2005	94,89	26,6
Detached	>2005	96,66	27,8
Semi-detached	<1945	365,83	23,6
Semi-detached	1946-1964	365,83	23,6
Semi-detached	1965-1974	295,30	23,3
Semi-detached	1975-1991	156,30	22,8
Semi-detached	1992-2005	89,70	26,8
Semi-detached	>2005	93,06	28,1
Cornerhouse	<1945	365,83	23,6
Cornerhouse	1946-1964	365,83	23,6
Cornerhouse	1965-1974	295,30	23,3
Cornerhouse	1975-1991	156,30	22,8
Cornerhouse	1992-2005	89,70	26,8
Cornerhouse	>2005	92,51	28,4
Rowhouse	<1945	385,09	20,8
Rowhouse	1946-1964	385,09	20,8
Rowhouse	1965-1974	261,72	23,7
Rowhouse	1975-1991	143,19	23
Rowhouse	1992-2005	76,15	27
Rowhouse	>2005	80,91	28,9
Appartment	<1945	215,39	20,8
Appartment	1946-1964	215,39	20,8
Appartment	1965-1974	174,25	21,4
Appartment	1975-1991	111,80	23,7
Appartment	1992-2005	65,76	27,5
Appartment	>2005	75,85	30,4

Table VII.2 Reference energy values (Agentschap NL, 2018)

VIII ENERGY USE IN BUILDINGS

Global energy usage in buildings

The building sector (residential and non-residential use) accounts for 30% of the global energy consumption. This sector accounts for almost two-third of halocarbon and 25-33% of black carbon emissions. A major part of this energy comes from renewables, electricity and natural gas. Although the use of renewables may seem positive, most of this source comes from traditional biomass, including wood, charcoal and dung. In non-OECD countries, traditional biomass remains the largest source of energy (IEA, 2013, 2017).

Giving a closer look at the building sector, the residential sector is responsible for relatively 22% of the final energy usage. The rest (8%) is used for non-residential purposes, e.g. commerce and public services. In the residential sector most of the energy is used for space heating (30%), cooking (33%) and water heating (20%) as seen in the figure below (IEA, 2017; 2015).

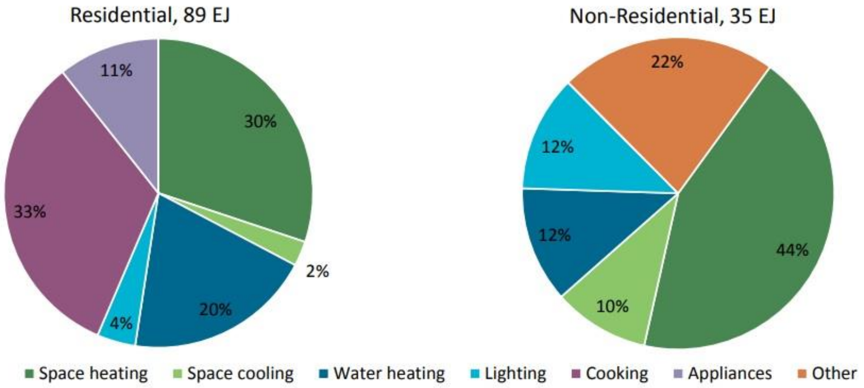


Figure VIII.1 Energy usage per function in buildings (IEA, 2015)

This pattern of energy consumption varies widely across countries and regions. This has to do with factors such as housing unit sizes, occupation density, climate, behaviour patterns and wealth. Some of these factors have a bigger impact than others, for instance climate. When looking at the future, major challenges will arise in the building and renovation sector. A major part (45%) of the heating and cooling demand to 2050 will come from existing buildings (IEA, 2013). These buildings are built according to less strict building standards. In the coming years, the demand for space cooling will grow rapidly as result of increased populations and income in hot regions during the same period (figure VII.2). The transition to more sustainable energy use in the buildings sector will require the wide deployment of more energy efficient buildings (IEA, 2013).

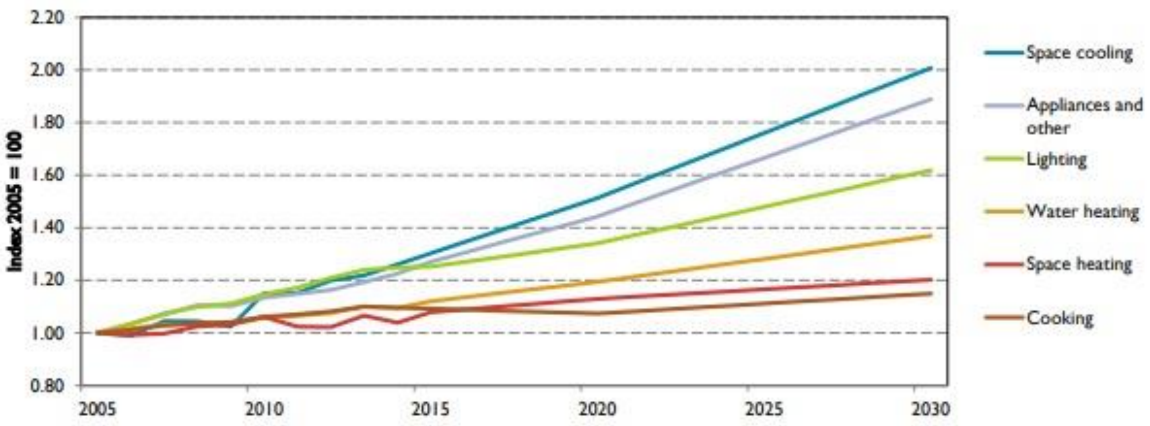


Figure VIII.2 Energy trends buildings (IEA, 2016)

Energy usage in the Netherlands

When looking at the Dutch housing sector it can be noted that this sector was responsible for approximately 22% of the total energy usage in 2016. Most of this energy comes from natural gas (71%). The rest of the energy comes from electricity (20%), biomass (5%), heat networks (3%) and remaining renewable heat (1%) or coal and oil (figure VIII.3) (Energieonderzoek Centrum Nederland, 2017; Rijksdienst voor Ondernemend Nederland, 2017a).

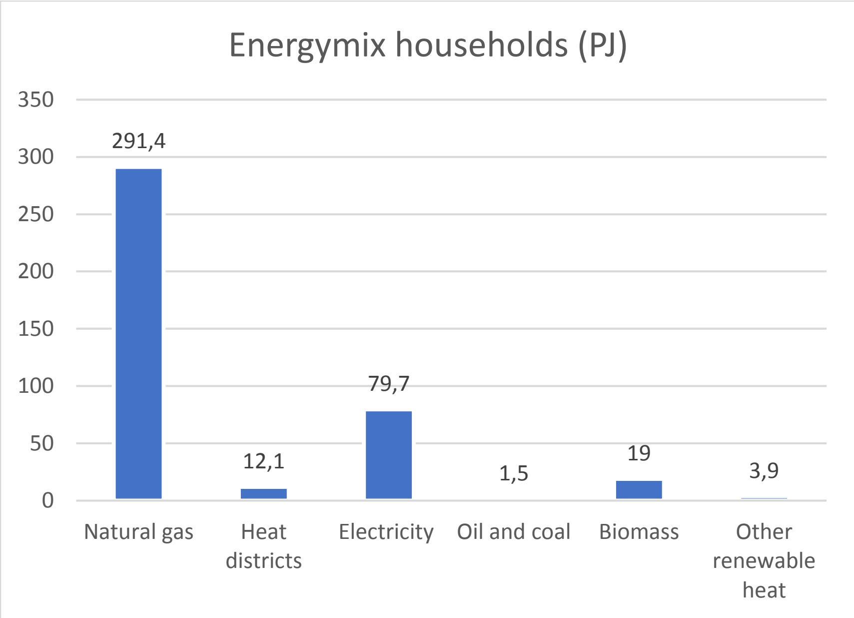


Figure VIII.3 Primary and secondary energy mix households in the Netherlands (Rijksdienst voor Ondernemend Nederland, 2017a)

In the residential sector most of the energy is used for space heating, which accounts for roughly 77%, more than double of the energy used for heating on a global level (figure VIII.1). natural gas is the most common source of energy for space heating (93%). The category 'other uses' accounts for the electricity consumption of non-building-related devices, such as televisions, dishwashers and refrigerators (Energieonderzoek Centrum Nederland, 2017; Rijksdienst voor Ondernemend Nederland, 2017a).

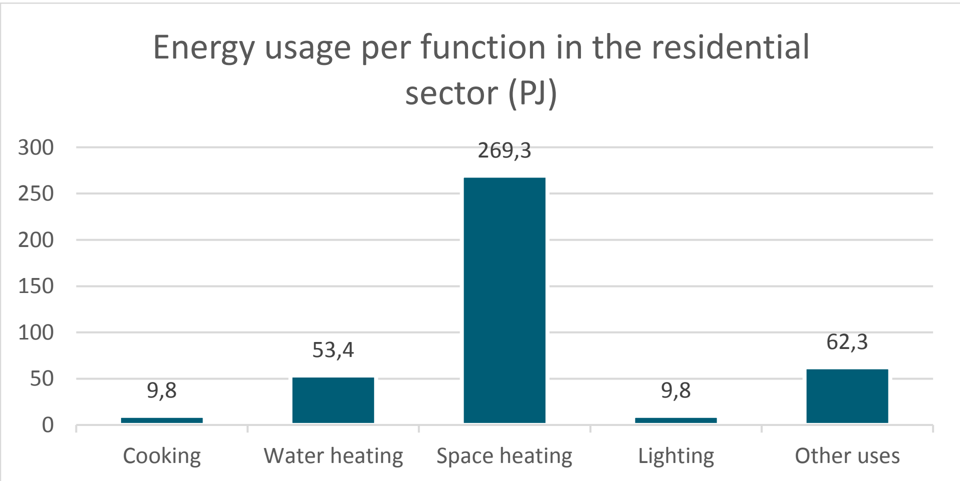


Figure VIII.4 Energy usage per function (Rijksdienst voor Ondernemend Nederland, 2017a)

Households have become more efficient in energy consumption. This is due to various factors including technical innovation and behavioural changes. Although gas is still the main source of energy for households, the total energy consumption has been decreasing since the seventies. This while the number of dwellings increases. In the Netherlands, about 85% of households have central heating on natural gas. Heating through individual stoves (local heating) is decreasing continuously. In apartment complexes it is becoming more common to replace block heating with individual boilers. Furthermore, the amount of heat supplied from heat networks is increasing as well and the use of electric heat pumps is increasing. New, but also existing homes have become much more energy efficient. This is the result of better-insulated houses and more efficient boilers. Insulating glass is standard nowadays in new homes in all rooms, but also floors, walls and roofs are well insulated (Energieonderzoek Centrum Nederland, 2016; Rijksdienst voor Ondernemend Nederland, 2017a).

In older homes this was not always the case, but in the past decades the insulation in these houses has improved much. Windows in living rooms are almost all double glazed and roofs are almost all insulated. Floors and exterior walls are insulated less often, but here too much has been improved the past decades. The increased energy efficiency also accounts for the electricity consumption. Electric appliances are becoming more and more efficient probably due to a larger share of more efficient electrical devices and lighting (Energieonderzoek Centrum Nederland, 2017; 2016; Rijksdienst voor Ondernemend Nederland, 2017a). Despite the increased energy efficiencies, energy savings and transition towards electrical heating sources, natural gas is expected to remain the most important source of energy for heating in the coming decades (figure VIII.5). Up to 2035 the importance of electric heat pumps will increase strongly under planned policy, although natural gas remains dominant (Energieonderzoek Centrum Nederland, 2017).

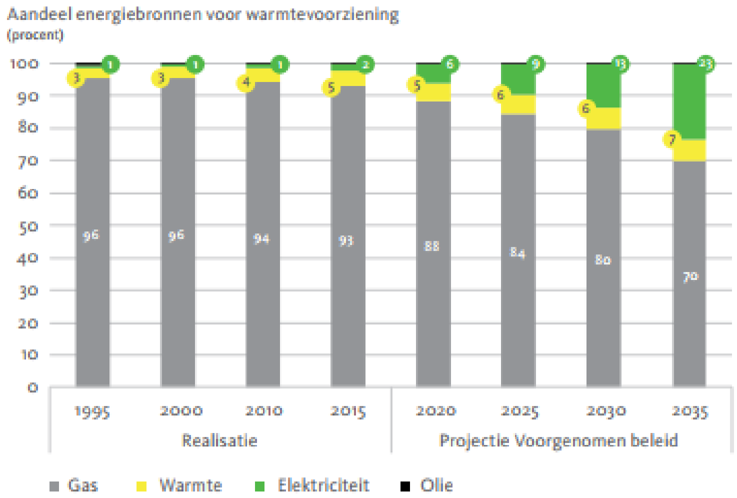


Figure VIII.5 Share of renewable sources for heating in the Netherlands (Energieonderzoek Centrum Nederland, 2017)

New devices are much more efficient and new lighting, white goods and other devices that fall under European Ecodesign requirements use less electricity. After 2020, there will be a tightening of requirements for some devices. This ensures that the electricity consumption of households will decrease until around 2025. Simultaneously, the amount of (hybrid) electric heat pumps in The Netherland/The EU will increase, which causes an increase in residential electricity usage. After 2025, the total electricity demand will rise yet again due to an increase in both building-related consumption and the total number of households, although most devices have been replaced by economical alternatives (Energieonderzoek Centrum Nederland, 2017).

IX EXISTING DATASETS

Certified energy labels (2017)

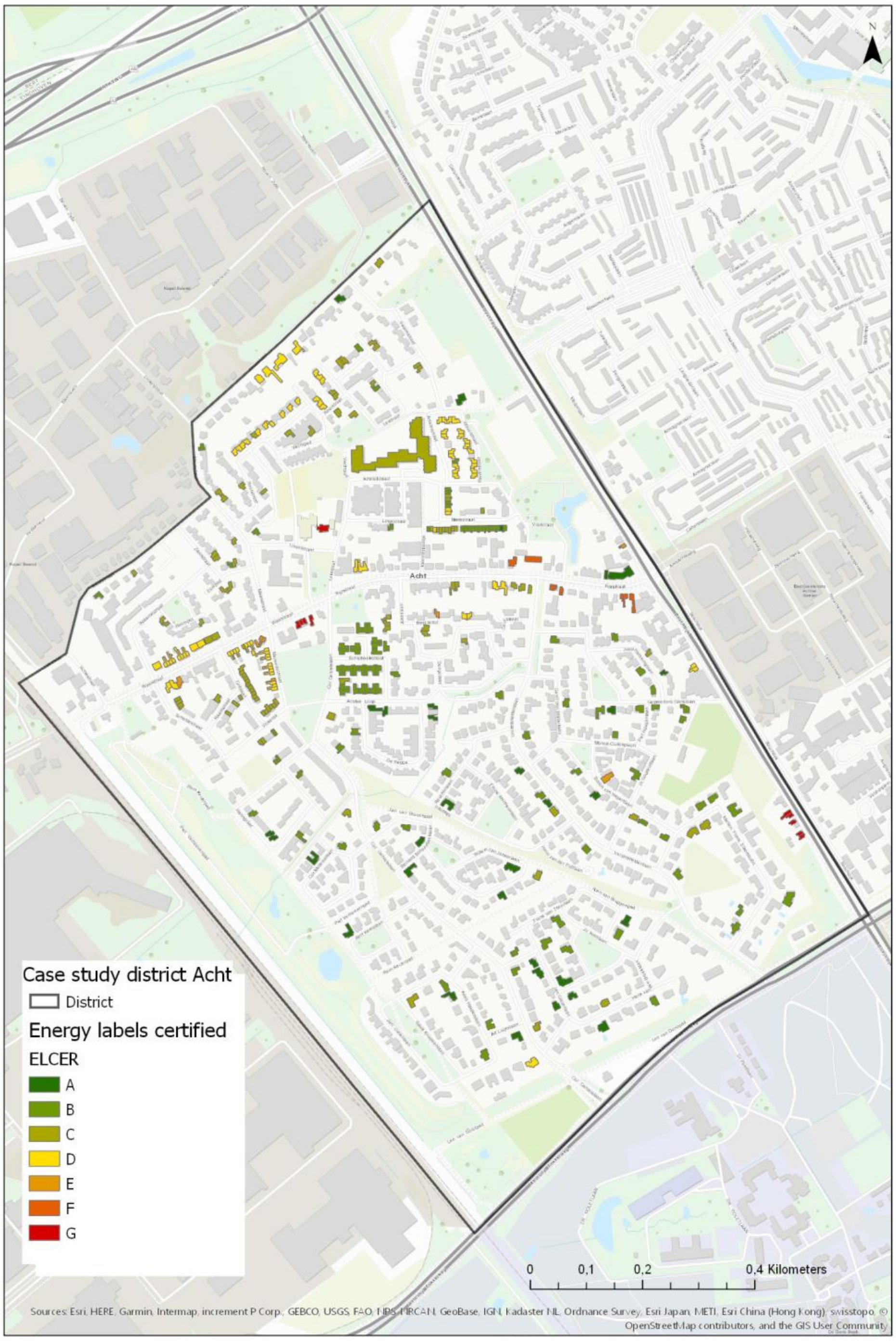


Figure IX.1 Certified energy lables

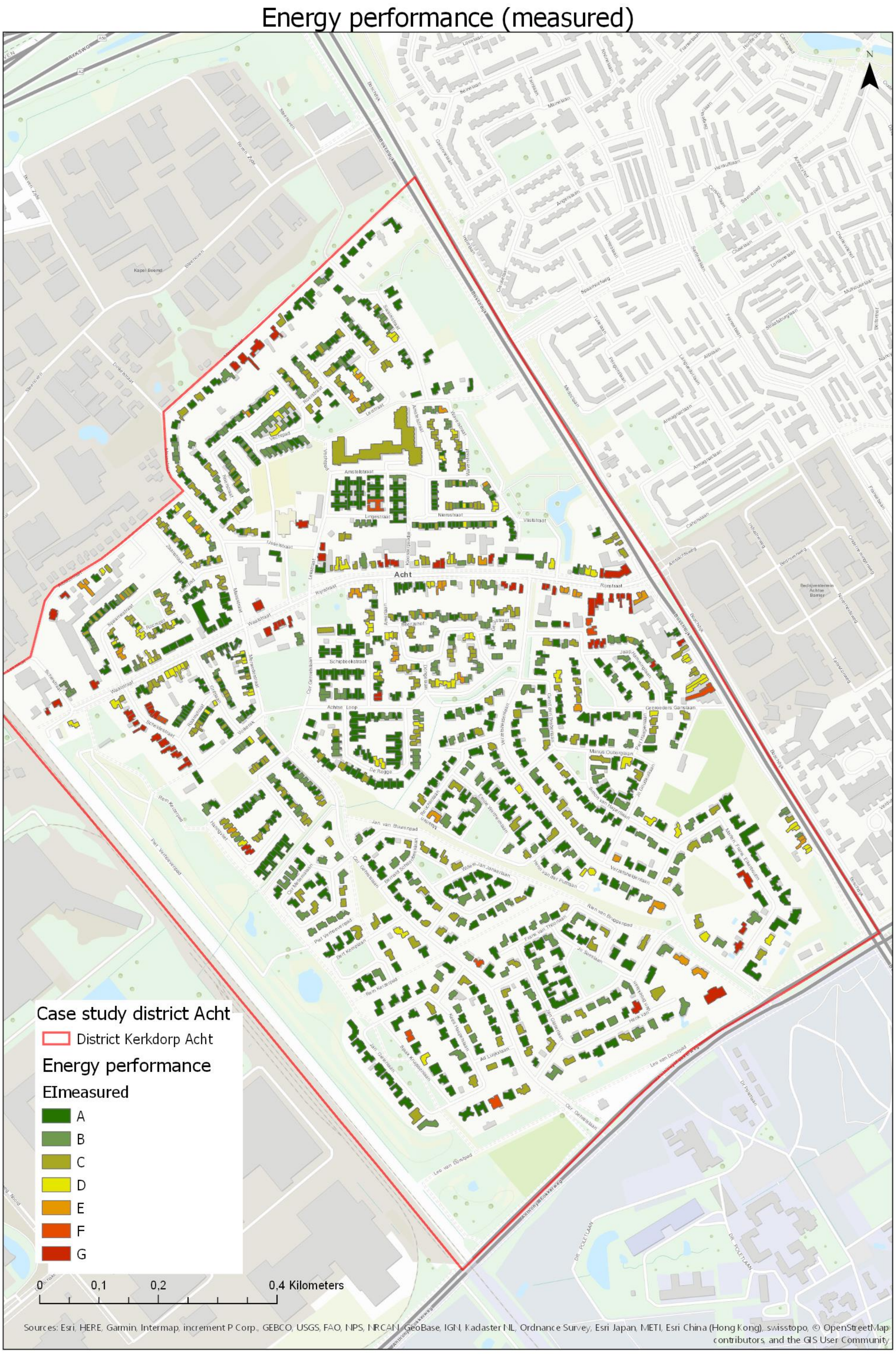


Figure IX.2 Measured energy performance

Construction period

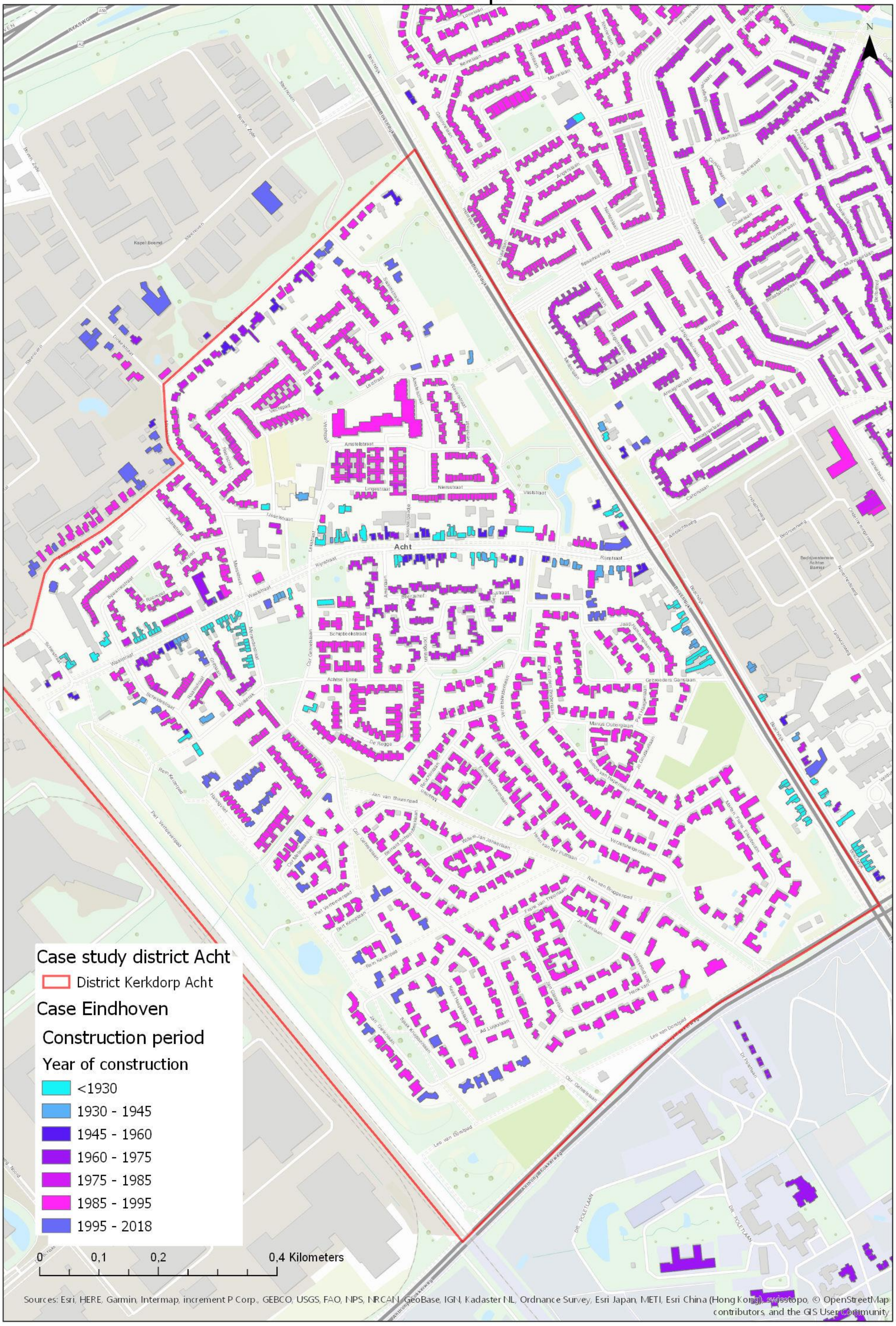


Figure IX.3 Construction periods

X RESULTS TESTCASE EINDHOVEN

Housing types Eindhoven

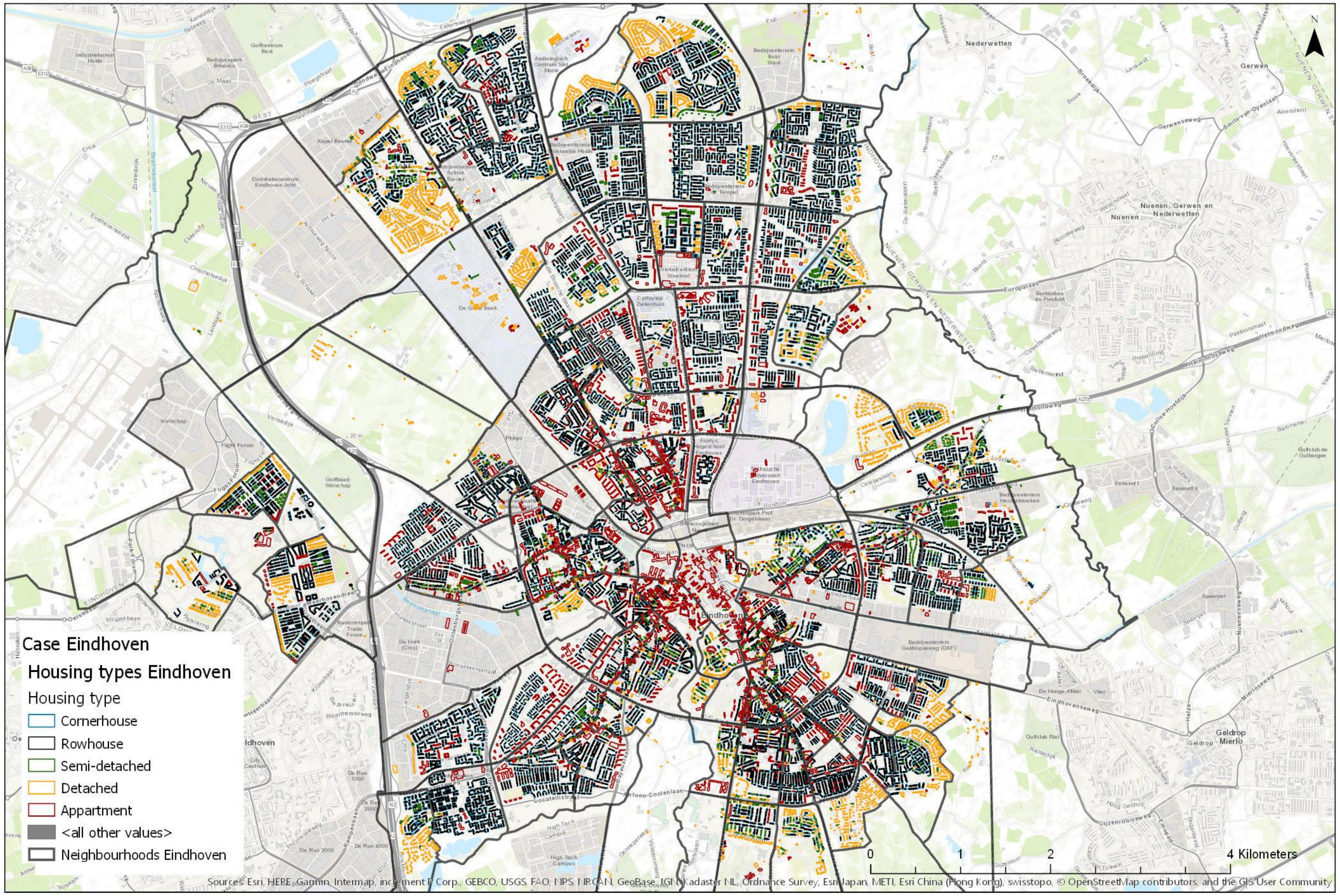


Figure X.1 Archetypes Eindhoven produced with the GIS-tool

Housing types

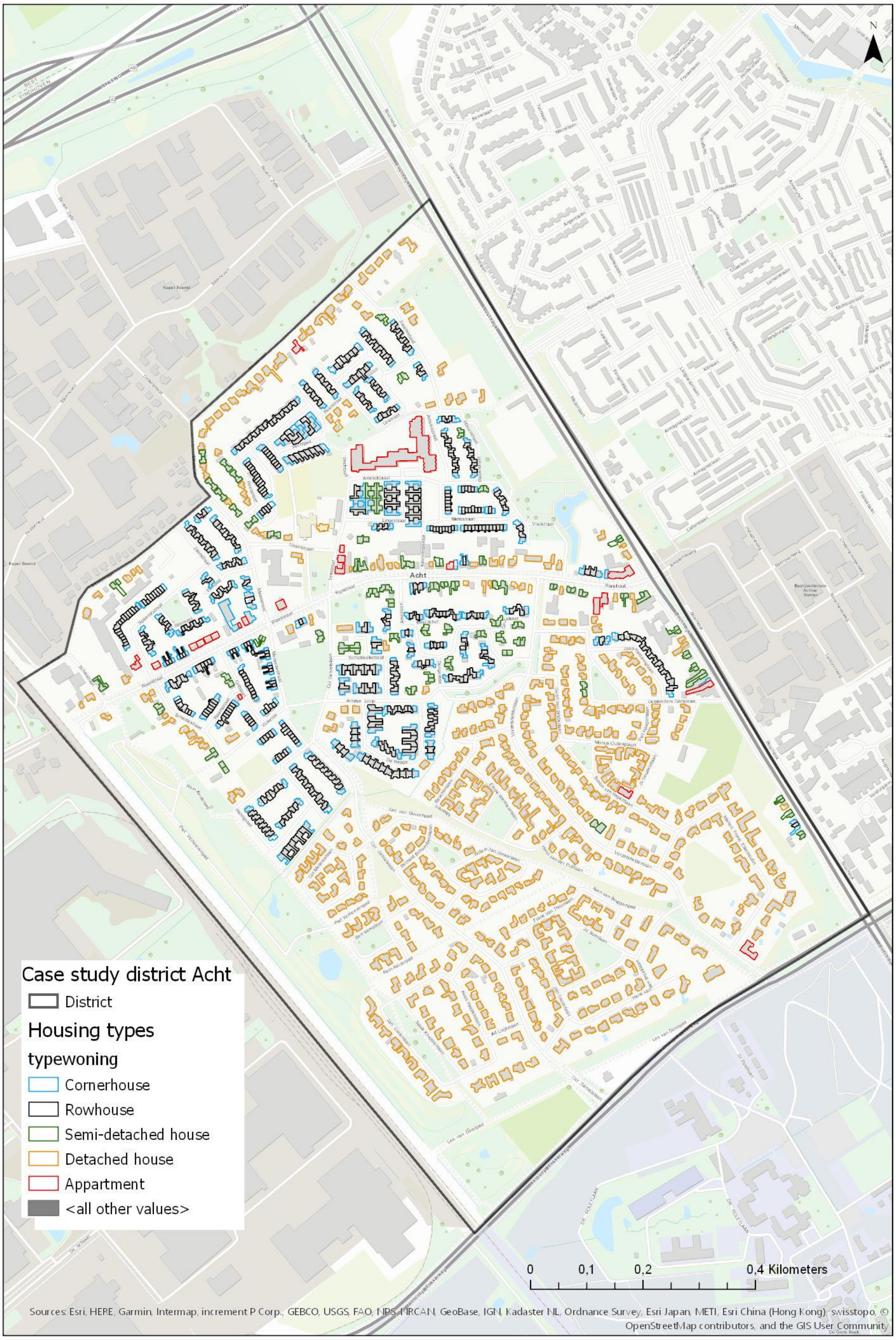


Figure X.2 Archetypes district Kerkdorp Acht produced with the GIS-tool

Sub housing types

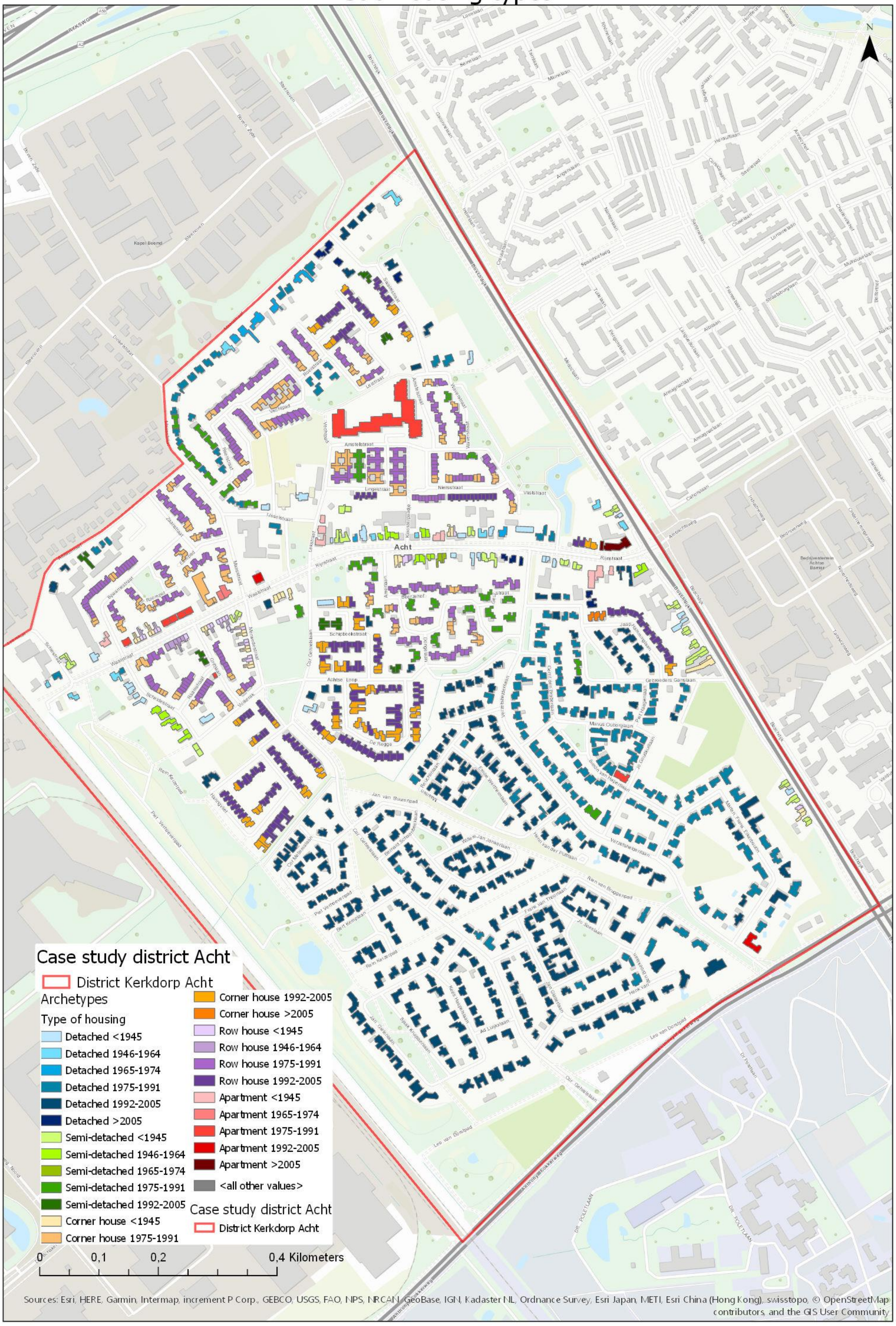


Figure X.3 Sub types of housing district Kerkdorp Acht produced with the GIS-tool

Figure X.4 Predicted gas demand by the statistical model

Figure X.5 Predicted electricity demand by the statistical model

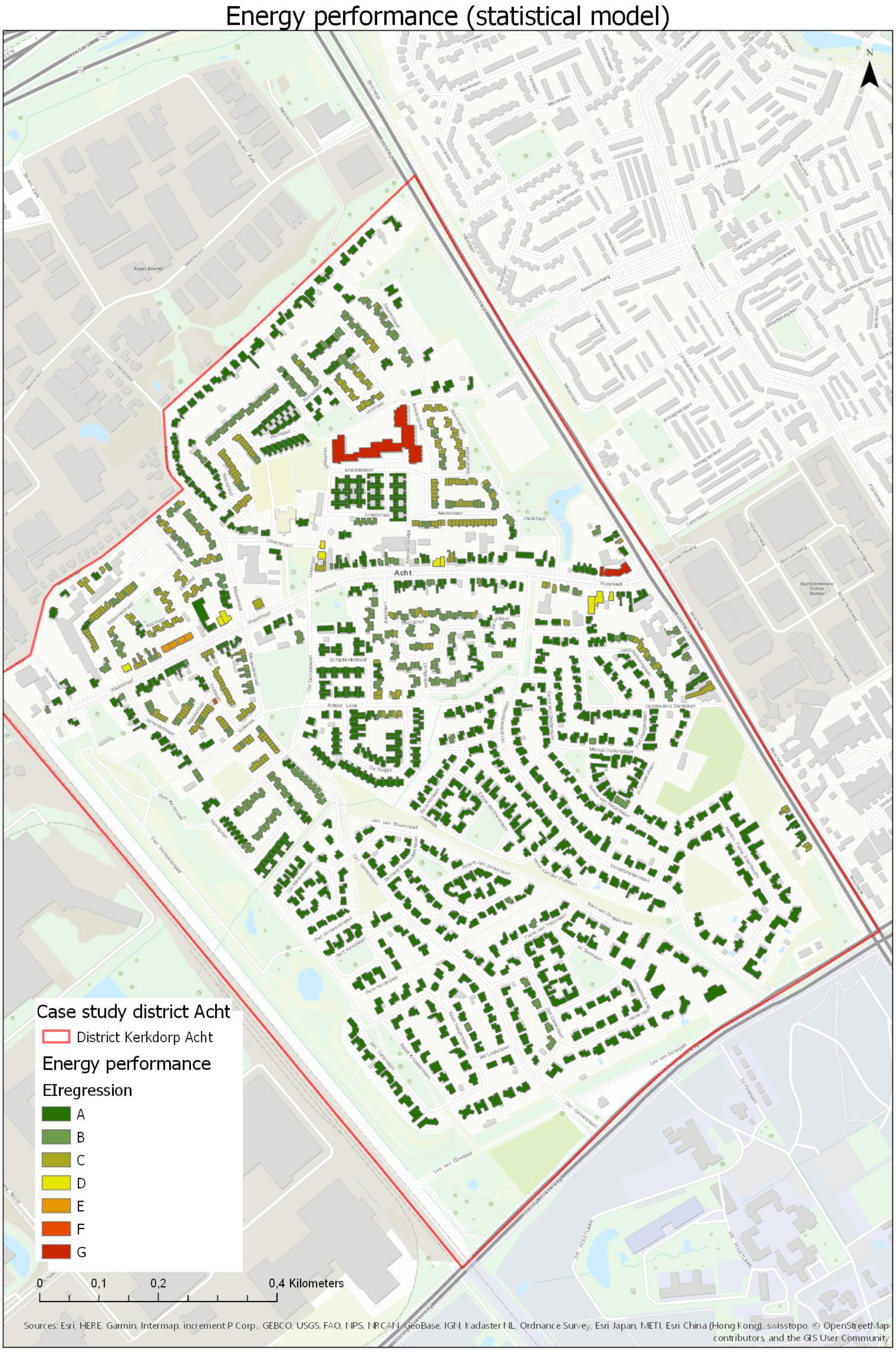


Figure X.6 Predicted energy performance indicated by energy labels (based on the statistical model)

Predicted gas consumption uniform model

Figure X.7 Predicted gas demand by the uniform model

Figure X.8 Predicted electricity demand by the uniform model

Energy performance (uniform model)

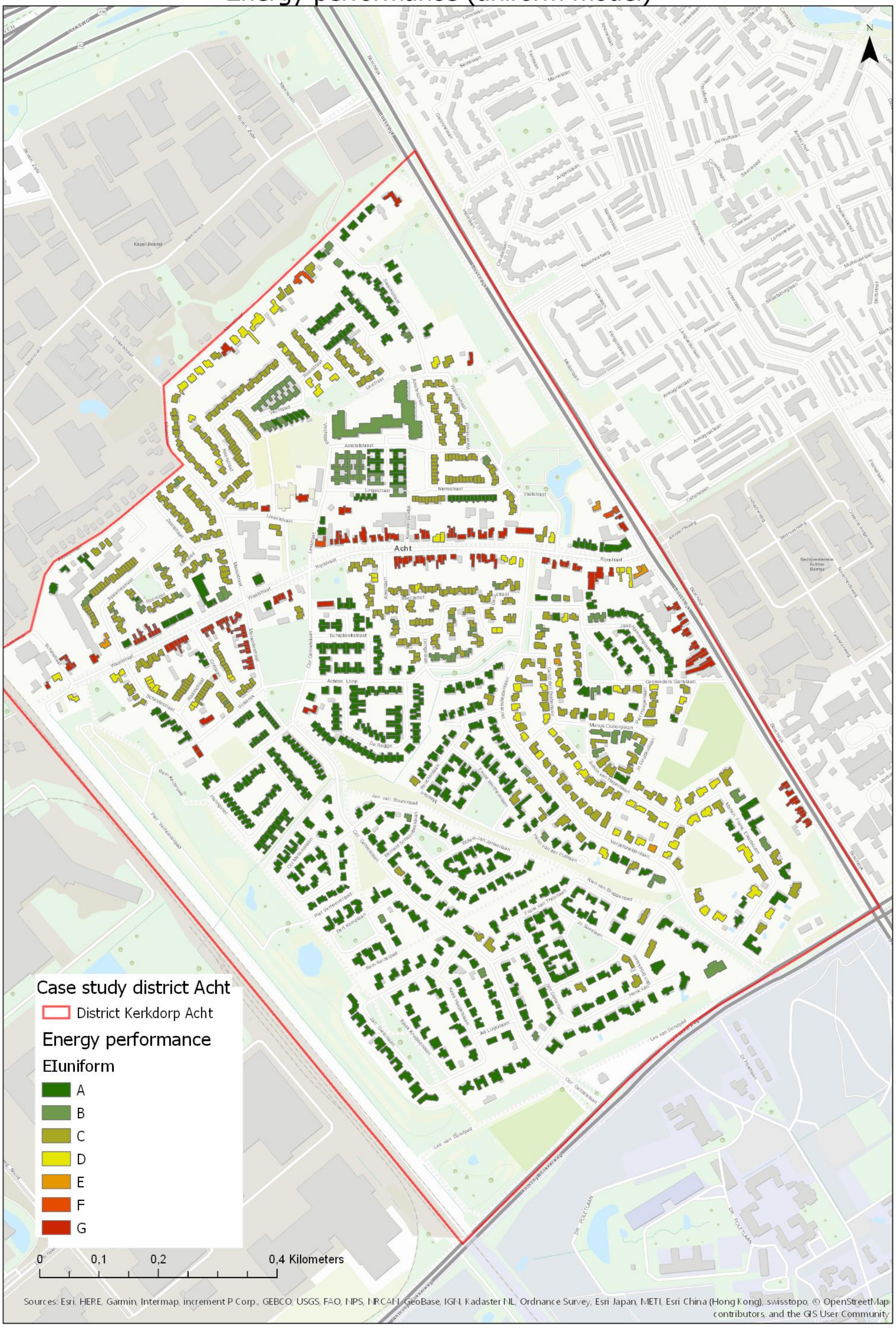


Figure X.9 Predicted energy performance by the uniform model

Figure X.10 Calculated potential energy reduction scenario I by the optimization tool

Figure X.11 Calculated potential energy reduction scenario II by the optimization tool

Figure X.12 Calculated potential energy reduction scenario III by the optimization tool

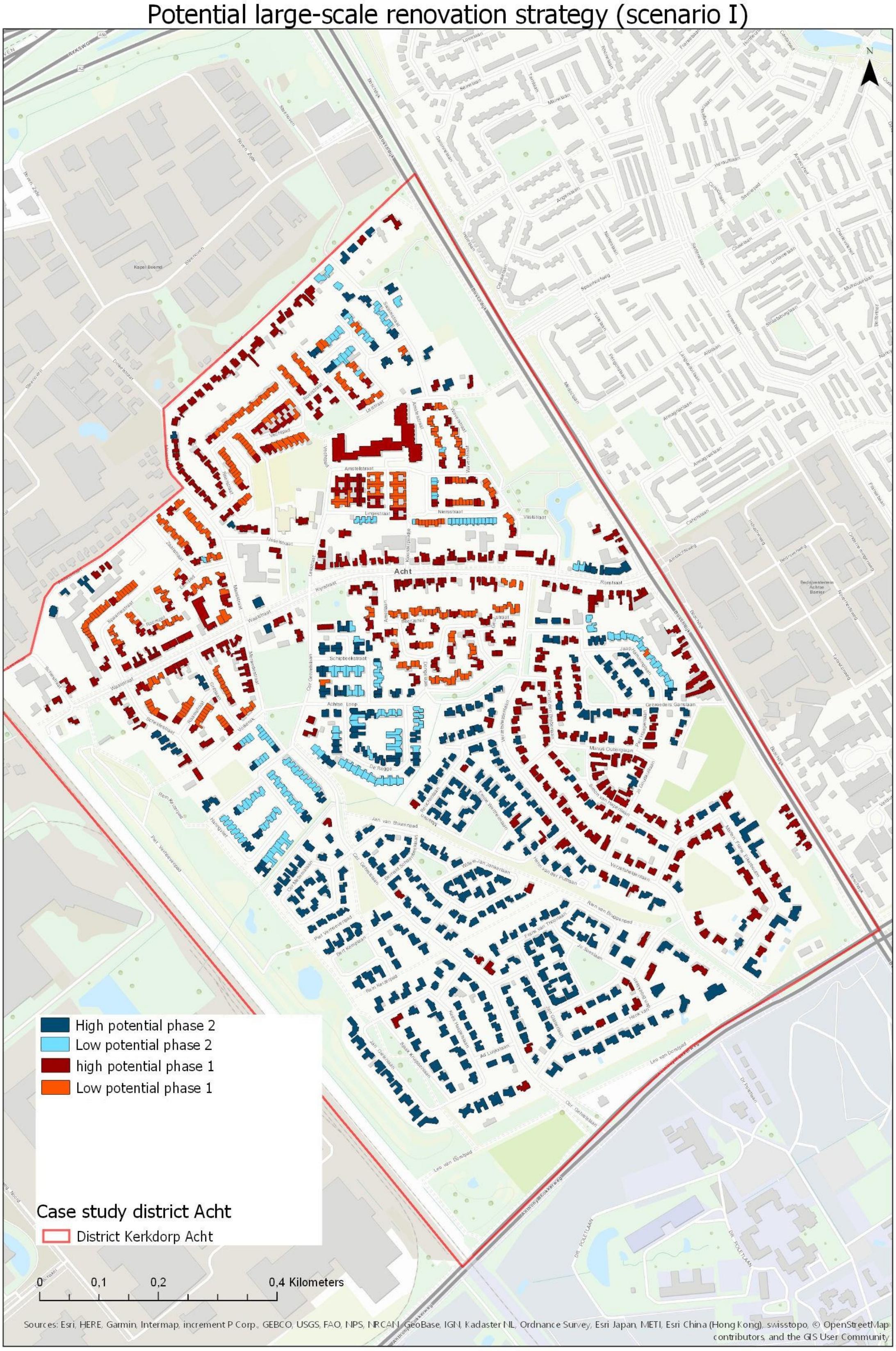


Figure X.13 Potential large-scale renovation strategy scenario I

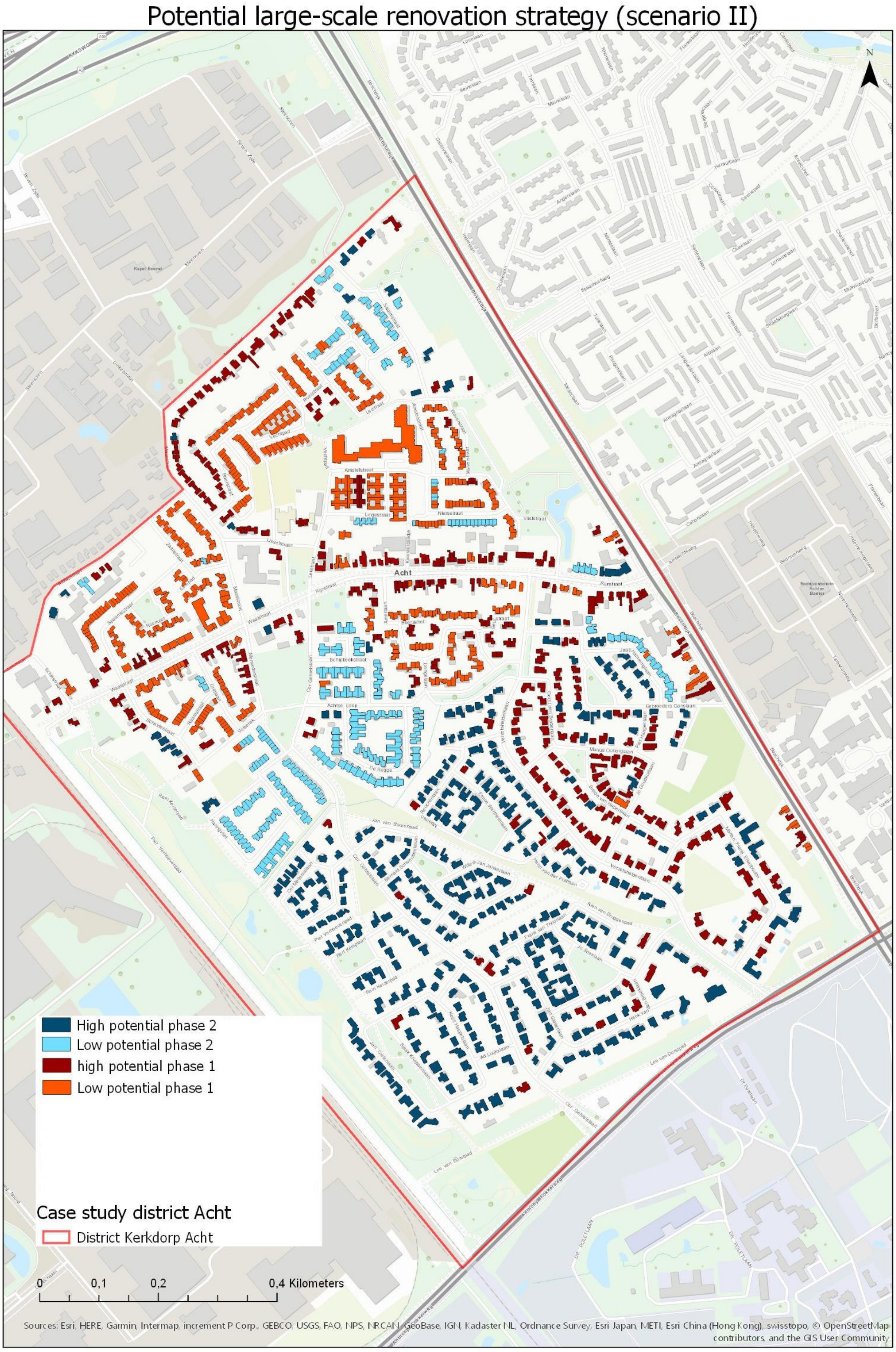


Figure X.14 Potential large-scale renovation strategy scenario II

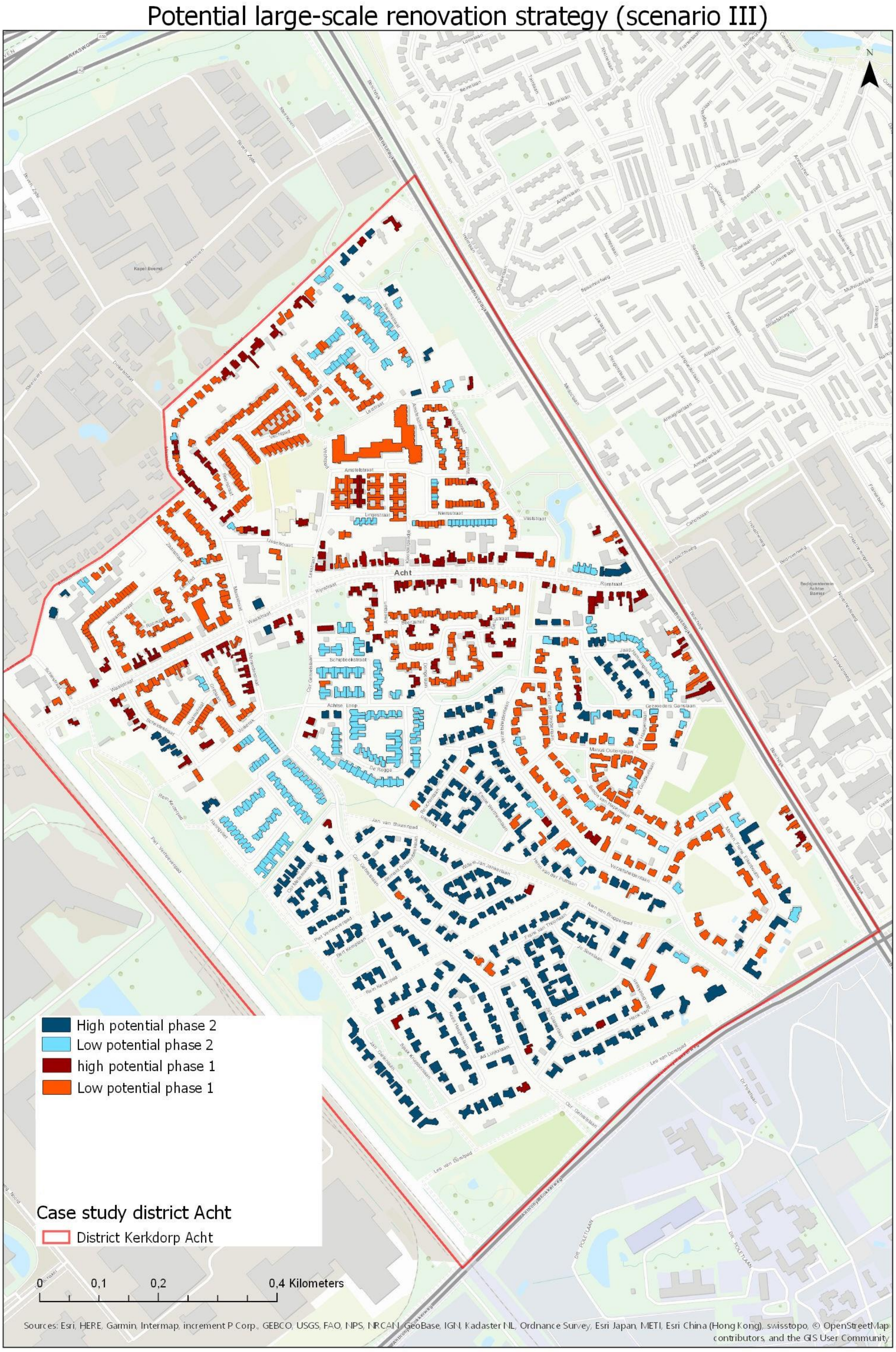


Figure X.15 Potential large-scale renovation strategy scenario III

Results regression model SPSS - gas prediction

Descriptive Statistics

	Mean	Std. Deviation	N
GAS	1623,98	569,50	356
occupants	2,37	,454	356
floorarea	134,04	41,05	356
Fisc	2503,46	862,85	356
det	,07	,16	356
semi	,05	,10	356
corh	,20	,08	356
row	,60	,21	356
app	,08	,17	356
B1945	,20	,30	356
B19461964	,26	,36	356
B19651974	,18	,34	356
B19751991	,21	,33	356
B19922005	,094	,21	356
B2005	,054	,16	356

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,631[a]	,398	,377	449,37

a. Predictors: (Constant), B2005, floorarea, B1945, occupants, app, B19922005, semi, B19461964, B19751991, corh, Fisc, det

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	45875182,133	12	3822931,844	18,931	,000[b]
	Residual	69265788,922	343	201941,076		
	Total	115140971,056	355			

a. Dependent Variable: GAS

b. Predictors: (Constant), B2005, floorarea, B1945, occupants, app, B19922005, semi, B19461964, B19751991, corh, Fisc, det

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	628,704	226,119		2,780	,006
	occupants	-100,011	55,583	-,080	-1,799	,073
	floorarea	2,876	1,220	,207	2,358	,019
	Fisc	,196	,044	,297	4,492	,000
	det	943,843	265,701	,274	3,552	,000
	semi	71,555	252,558	,013	,283	,777
	corh	1263,216	439,728	,184	2,873	,004
	app	269,365	195,667	,081	1,377	,170
	B1945	296,327	96,269	,158	3,078	,002
	B19461964	127,336	88,771	,080	1,434	,152
	B19751991	-128,800	97,300	-,075	-1,324	,186
	B19922005	-299,371	139,065	-,111	-2,153	,032
	B2005	-459,691	159,191	-,129	-2,888	,004

Coefficients[a]

Model		Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)		
	occupants	,889	1,124
	floorarea	,227	4,411
	Fisc	,400	2,497
	det	,294	3,401
	semi	,810	1,234
	corh	,425	2,351
	app	,512	1,953
	B1945	,666	1,501
	B19461964	,565	1,771
	B19751991	,551	1,813
	B19922005	,660	1,515
	B2005	,880	1,136

a. Dependent Variable: GAS

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance	VIF
1	row	.[b]	.	.	.	,000	.
	B19651974	.[b]	.	.	.	,000	.

Excluded Variables[a]

Model		Collinearity Statistics Minimum Tolerance
1	row	,000
	B19651974	,000

a. Dependent Variable: GAS

b. Predictors in the Model: (Constant), B2005, floorarea, B1945, occupants, app, B19922005, semi, B19461964, B19751991, corh, Fisc, det

Results regression model SPSS - electricity prediction

Descriptive Statistics

	Mean	Std. Deviation	N
ELC	3637,02	1299,51	326
Occupants	2,43	,43	326
floor	128,07	40,24	326
Fisc	2496,11	843,68	326
Det	,06	,16	326
Semi	,047	,10	326
Cor	,18	,09	326
Row	,50	,24	326
App	,22	,28	326

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics R Square Change	F Change
1	,608[a]	,370	,356	1042,855149075488700	,370	26,665

Model Summary

Model	Change Statistics df1	df2	Sig. F Change

1	7	318	,000

a. Predictors: (Constant), App, Fisc, Occupants, Semi, Det, Cor, floor

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	202997730,990	7	28999675,856	26,665	,000[b]
	Residual	345839902,101	318	1087546,862		
	Total	548837633,091	325			

a. Dependent Variable: ELC

b. Predictors: (Constant), App, Fisc, Occupants, Semi, Det, Cor, floor

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	784,645	573,906		1,367	,173
	Occupants	-25,045	144,314	-,008	-,174	,862
	floor	17,289	2,795	,535	6,186	,000
	Fisc	,187	,095	,122	1,968	,050
	Det	214,126	606,410	,027	,353	,724
	Semi	293,285	682,286	,022	,430	,668
	Cor	62,589	1206,923	,004	,052	,959
	App	895,545	384,906	,195	2,327	,021

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	-344,487	1913,777
	Occupants	-308,976	258,886
	floor	11,791	22,788
	Fisc	,000	,375
	Det	-978,956	1407,209
	Semi	-1049,081	1635,651
	Cor	-2311,975	2437,152
	App	138,260	1652,829

a. Dependent Variable: ELC

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Row	.[b]	.	.	.	,000

a. Dependent Variable: ELC

b. Predictors in the Model: (Constant), App, Fisc, Occupants, Semi, Det, Cor, floor

XI TECHNICAL EXPLANATIONS

Energy demand and consumption

In general the energy demand represents the rate of which energy is consumed. This can be measures in Watt or Joules. The energy consumption represents the energy consumed over a certain time period. This can be measured for instance in Watt/hour or Joules/second. The energy demand can be derived from the energy consumption, by dividing the consumed energy by the certain time period. In the energy performance calculations, the total energy demand over a year is used (Qtotal). The energy demand over a year is equal to the energy consumed over a year. The following conversion values were used in this thesis (Energieconsultant, n.d.):

1 m^3 of gas = 35,17 MJ
1 kWh = 3,6 MJ

R_c and Rd value

The R_c value stands for the thermal resistance of a building component. Rc and Rd values are concepts that are often used when it comes to insulating buildings. The values indicate how well the heat is blocked by a material or a construction. An Rd value is the heat resistance of a material. The d stands for 'declared', the value as specified by the manufacturer. The higher this number, the more heat is retained. And so, the better the heat resistance. Rd is also often referred to as R-value. The Rc value is the heat resistance of an entire structure. This could be, for example, a roof or a cavity wall. The Rc value indicates the insulating capacity of the entire structure. The higher the number, the more heat is retained. The Rc value is indicated in m^2K/W. In the current building decree, the requirements for new houses have been tightened up to:

- Floor: Rc value at least 3.5 m2K / W
- Facade: Rc value at least 4.5 m2K / W
- Roof: Rc value at least 6.0 m2K / W (Energiebespaarlening, n.d.)

U-value

The U-value is used for determining the thermal performance of windows. It is important to limit heat loss through glazing. The insulation value of glass is shown with the U value. This is the amount of heat that is lost through the glass. The lower the U value, the less heat is lost and the better the insulating effect of the glass. The U value is expressed in W / m^2K or the amount of heat (Watt) that is lost by a square meter (m^2) of glass at a temperature difference of 1-degree Kelvin (K) between the inside and outside of the glass (Luchtdicht bouwen, n.d.).

XII DESCRIPTION RENOVATION STRATEGIES

Strategy	Replace	Add-in	Wrap-it	Add-on	Cover-it
Description	The replacement of the old building components	Improve the building components from within	The building is covered with a second layer	New building components are added on the existing construction	The entire building is covered with an external construction
Renovation measure(s)	- Replace the complete building envelope - Replace elements	- Internal insulation - Cavity insulation	- External insulation, - Cladding of the balconies - Second building layer	- Adding new elements (e.g. balcony) - New building as an extension - Additional floor	- Cover parts or entire building - Heated or unheated space
Renovation scale	Large to very large	Small to medium	Medium to large	Medium to large	Medium to large
Advantages	- New components with better performance - More variables for energy optimization and flexible design	- Adequate for monumental status - Increase the thermal resistance	- Solve thermal bridges - Increase the thermal resistance - Different cladding possibilities - Little disturbance	- New facade with better performance - Increase space - Functional benefits	- Create thermal buffer - Enhance natural ventilation with stack effect - Out-dated facade no longer exterior - Additional space
Disadvantages	- Big impact on the users and high costs	- Critical connection thermal bridging need attention - Big disturbance for users	- Not applicable to monumental buildings - Possible space limitation	- Needs to be combined with other strategies for facades non-adjacent to new structure - Structural limitation	- Not applicable to all cases - Depending on layout and function of the building - Overheating risk

Table XII.1 Description renovation strategies (Balkuv, 2017; Konstantinou, 2014)

XIII TRANSCRIPTION INTERVIEW

Interview Sander Hartwig, the Efficiator

Date: 04-07-2018
Interviewee: Sander Hartwig, co-founder The Efficiator
Interviewer: Rick Dijkstra
Interview duration: 102 minutes
Location: Schiedamse Vest 154, Rotterdam
Interview recording device: voice recorder

S: Sander Hartwig
R: Rick Dijkstra

After a short introduction of both attendees, an interview was held regarding the online-tool: the Efficiator, and how it works and what kind of parameters it uses.

S: Even kort vertellen wie ik ben, wat ik doe en wat Efficiator doet. Ik ben zelf Sander Hartwig, ik ben een beetje, ja, ze noemen me de whizzkid. Op elke vraag moet ik het antwoord hebben. Ik heb dat helaas nog niet, maar dat komt gaandeweg, komt dat wel. Ik ben vooral verantwoordelijk voor de operaties. Hoe kunnen we dit implementeren. Ehm, daarnaast gaan wij nu dus ons eerste project gaan doen in een wijk, ehm, past het heel mooi in het interview wat je wilt afnemen. Uiteindelijk willen met Efficatior, na de Efficiator is een online-tool. Waarmee je woningeigenaren heel eenvoudig één keuze hoeft te maken: ik wil verduurzamen. Als je die keuze maakt. Dan regelen wij alles wat daarbij komt kijken.

R: Ja precies.

S: Dat zijn alle zijden, financiële vraagstukken die je hebt, subsidies, welke installateur moeten we hebben, welke producten moet je hebben, wat moeten die waardes daarvan zijn. Dat vullen we allemaal op voorhand in. Wat wij laten zien is een resultaat: je gaat zoveel CO2 besparen, jij gaat zoveel investeren, dit is het gevolg voor je energierekening, die gaat zoveel naar beneden. Je comfort gaat omhoog, je woningwaarde gaat omhoog. Dat maken wij inzichtelijk. Maakt dat een beetje vergelijkbaar met een auto. Je wilt een sleutel hebben, starten. En je wilt niet weten dat je eerst met een sleutel dat je eerst een infrarood signaal moet sturen naar de auto toe. En dan gaat er een stroompje door de auto de auto lopen en dan met de bougies werken. En die genereert een vonk. Dat wil je allemaal niet hebben. Het moeten starten, lopen zijn. En dat is ook iets wat wij willen aanbrengen. En daarmee verwachten wij dat we wel succesvol kunnen zijn in het overtuigen van de bewoner tot het zetten van acties.

R: Ja precies, oke. En, wat is jouw achtergrond precies?

S: Ik heb het IPA gedaan in Driebergen. Dat is een instutuut voor automotormanagement Business school. Dat is een mondvol, maar eigenlijk komt het erop neer dat ik ben opgeleid om mijn eigen autodealer te beginnen. Maar ik vind auto's leuk om in te rijden, maar minder leuk om te verkopen. Ik wel wat toevoegen aan de maatschapij, tenminste ik heb het gevoel dat ik dat meer kan doen met duurzaamheid. Dus zo doende, maar uiteindelijk gaat het om, hoe run je een bedrijf, hoe maak je een strategie. Hoe werk je met sales, marketing, rechten, techniek. Dus ik heb alle vlakken gehad, dus ik weet van heel veel weining. Maar daarvoor heb je altijd weer mensen die van weining heel veel weten. Dus dan kan je een mooie match maken.

R: Ja, ik heb een beetje hetzelfde. Ik weet overal het topje van de ijsberg, qua milieu en duurzaamheid. Maar ik ben geen expert in alles zegmaar.

S: Nee, nee. Maar dat gaat denk ik ook niemand lukken want dan zul je een stuk of dertig studies moeten doen. Voordat dat je aan de bak kan, kun je met pensioen. Dat moet je ook niet willen.

R: oké dus die effiator, ehm. Dat is gewoon een willekeurige wooneigenaar hun data invullen ofzo, hoe werkt dat?

S: Na, kijk. Je hebt heel veel online tools in de markt, bijvoorbeeld een greenhome, energiebespaardes. Die werken met een online vragenlijst en dan komt daar generieke informatie uit van, dit is het. Wil je dit hebben ja of de nee. En daarom moet een installateur komen en moet dat op maat maken. Daarbij zien we bij elk proces heel veel drempels. Wij hebben gekeken, hoe wie die drempels kunnen slechten. Dus dan wil je van tevoren de informatie van de woning weten. Want mensen vinden het verschrikkelijk om ergens energie in te stoppen en niet zeker weten of ze iets terug krijgen. Dus daarom hebben we besloten voor een regio aanpak. Dat gaan we dus eerst doen met een wijk. Alleen ons idee is om met een grote partner, bijvoorbeeld een bank. Om daarmee in 1 keer 50.000 van zijn hypotheek portefeuille te targeten. En dan krijgen ze dus allemaal mailing met een account. En dan hebben wij van tevoren de data verzameld. Dus daar moeten ze voor betalen, dus vandaar dat je het ook via een grote partner doet. En dan heb je dus eigenlijk al, een kant en klaar adviesrapport wat veel nauwkeuriger is omdat je op voorhand al vragen hebt ingevuld. Want de bewoner weet gewoon een hele boel niet. Die weet niet wat zijn energieverbruik is, die niet wat zijn gasverbruik is, zijn elektraverbruik is. Die weet misschien wat hij maandelijks betaald, maar dat klopt ook al niet. Want je kan gigantische voorschotten betalen en dat klopt nog steeds helemaal niks. Dus je moet echt die informatie hebben.

R: Ja inderdaad, oké. Ja. Nee precies. Even kijken, wat voor informatie zit er al in die jullie dan als het ware vergaren. Hoe categoriseren jullie het. Op een gegeven moment moet je heel veel technische informatie en kennis hebben.

S: Uiteindelijk wel, alleen je hebt altijd wel wat generieke oplossingen. Waardoor je een goeie schatting kan maken. Uiteindelijk zul je altijd een mens op locatie moeten hebben die dit controleert.

R: Ja klopt.

S: Dus dat hebben wij ook zo ingezet. Maar wat je wel voorhand kan doen. Er zijn bepaalde besluiten bekend. Eh, niet als in online. Maar je weet in ieder geval wel wat voor isolatiewaarde een bepaalde muur heeft. Daar, op die aanname kan je voorboorduren. Dus stel je weet de isolatiewaarde van een muur, de nieuwe isolatiewaarde. En dan kan je daarover wat zeggen over de besparing die je daarmee gaat opleveren.

R: Ja precies.

S: Daar heb je allemaal natuurkundige formules voor. Dat is een kwestie van een berekening, dus het opmeten van vloeroppervlak, muuroppervlak, dakoppervlak en dan gooi je daarna daar een aantal formules doorheen en dan kan daar een uitkomst uitkomen. En dan is het daarna alsnog aan de installateur om te kijken of het bouwtechnisch wel kan.

R: Ja exact.

S: Dus eerst creëer je de wens, dan ga je kijken wat kan, daarna ga je het doen voor wat mogelijk is.

R: Dus op basis van ehm, je hebt een wijk zeg je nu waarvoor je het uitvoert. Je hebt het dus niet ergens anders nog uitgevoerd.

S: We hebben een losse woning gedaan met wat handmatige scans. Maar we gaan nu de eerste automatisering stap doen. Dat is de fase waarin we nu in zitten. Ze zijn er nu een tool voor aan het bouwen waarmee je in 1 keer 4000 woningen tegelijkertijd scannen. Ehm, dat is zeg maar waar we nu staan.

R: Oke, en je scant dus op, ehm, basis van de gegevens die je van de bank krijgt.

S: Deels, deels van de bank, maar een bank heeft weinig informatiegegevens boven de NAW gegevens, dat weten ze. Ehm, ze weten wie in hun huis zit, ze weten de waarde van de woning. Ehm, dus daar willen wij graag mee rekenen. Maar als je bijvoorbeeld kijkt naar data over het stroomverbruik. Dan moet je naar een energieleverancier of een netbeheerder. Want zij hebben dat en dan moet je een samenwerkingsovereenkomst sluiten met hen.

R: Oke.

S: Dus daarom zijn we ook in gesprek, om te kijken of we Stedin als partner kunnen krijgen. Uiteindelijk hebben zij ook een uitdaging omdat ze van het gas af willen. Dus zo moet je eigenlijk een ecosysteem van verschillende partijen en dat is eigenlijk per drempel heb je een partij nodig. Dus zo is altijd 1 partij die je drempel slecht, sommige doen er wat meer. En dat begint dus bij informatie. De woningeigenaar weet dat niet, die drempel moet je slechten dus daarvoor zet je een groot energiebedrijf neer die daarbij weet. Dan heb je daarna het maken van de keuze, die drempel willen wij dus zelf slechten. Dit is het advies, vertrouw ons hier hebben wij hebben hier goed over nagedacht, dit kan je doen. Dan heb je nog de drempel van, hoe zoek ik nou een goede vakman die dit werk kan doen. Daarmee moet je dus van tevoren installateurs controleren, recensies daarover hebben, vergunningen en erkenning en certificaten en noem het allemaal maar op. Dan heb je daarna nog van hoe ga je dit allemaal bekostigen, dan komt dus de bank kijken. Ehm, die hebben allemaal financiële constructies waarop ze dus de woningeigenaar kunnen helpen. Dus je kan dit doen via de hypotheek, persoonlijke lening. Ze zijn nu ook bezig met een gebouw gebonden financiering. Maar dit staat nu nog in de kinderschoenen. En dan heb je uiteindelijk om voor ons om voor de bewoner, voor alle partijen om te kijken, klopt dit wel. Heb je nog een monitoringaspect nodig van hé, we hebben een berekening gedaan, die moet je natuurlijk over een jaar heentrekken. Het heeft geen zin om alleen drie zomermaanden te pakken, dan klopt er niks van. Dus dan moet je naar een jaar kijken, klopt dit wel? Dus dan moet je ook een jaar lang informatie verzamelen over de woning.

R: Oke en de doelgroep, wat voor type woningeigenaren hebben we het over, hebben we het ook over woningcorporaties ofzo?

S: Woningcorporaties kunnen, alleen bij een corporatie heb je meerdere ja's nodig. En bij woningeigenaren heb je 1 ja, een ja of een nee. Dus dan kan je makkelijk in de straat als 1 iemand zegt: ja, dan kan je die helpen. Maar als je met een woningcorporatie werkt dan heb je een lang traject en daardoor is dat te tijdsintensief om dat geautomatiseerd te doen. Maar het wordt wel degelijk gedaan door energieadviseurs. Het is alleen voor ons is het alleen een te arbeidsintensief trajet en valt niet binnen onze online-scope.

R: Nee precies, het is puur gericht op koopwoningen en private huurders ook of?

S: Ehm, nee want dan praten we liever met de woningeigenaar daarvan. Ehm maar dat is zijn ook weer lastige gesprekken want die hebben er een huurder onder zitten. Voor nu is het woningeigenaar en gelukkig hebben we daar 4 miljoen van in Nederland dus zijn we wel eventjes zoet mee. Maar daarnaast hebben we ook wel een afsplitsing gemaakt in woningtypes. Want wij gaan niet een woning van na 1992 kunnen wij niet gaan upgraden. Want omdat dat gewoon financieel veel minder rendabel is. De muren zijn voldoende geïsoleerd en als je dan dus volgens de NOM ehm energiebesparingswaardes gaat werken, ja dan duurt het gewoon 30 jaar voordat je dat terug hebt verdiend als het niet langer is. Dus dat krijg je niet verkocht, dan krijg je geen leuk financieel plaatje voor. Dus dan moet je gewoon een veel grotere warmtepomp aanbieden, daar blijven we dus liever nog even van af. Waar we zo ongeveer op richten zijn woningen tussen 1930 en 1992.

R: Oke, daar is ook de grootste slag te maken, dat is ook weer zo. En dat advies, dat doen jullie ook automatisch of is dat handwerk?

S: Dat is automatisch dat is ehm, we krijgen wat informatie naar binnen. Eh dat doen we ook met bijvoorbeeld met informatie die het kadaster heeft, en een concurrent van Funda. Daar gaan we een stapje verder met de informatie verschaffing. Ehm, dus zij leveren ons informatie en daardoor kunnen wij met al die informatie kunnen wij een berekening maken en daar komt wat uit. Natuurlijk zal dat een bandbreedte hebben wat wel kan en wat niet kan. Als iemand een aanbouw heeft gedaan en dat is nergens geregistreerd dat kunnen wij niet van tevoren weten. Maar wat we daar anders doen is, we hebben ingebouwd dat iemand een rapport krijgt en dan komt altijd een installateur langs om eerst te verifiëren, kan dit wel. En dan gaat hij dus alles nauwkeurig opmeten en dan komt die informatie terug in de database en kunnen we dus met 1 woning, als je een rijtje hebt, dan kun je daar weer standaarden in gaan zoeken en kan je dat weer extrapoleren. Daardoor wordt de tool steeds nauwkeuriger, maar je moet ergens beginnen.

R: En wat voor advies is het dan, is het gewoon heel basaal van spouwmuurisolatie toevoegen. Is het specifiek op maatregel gericht, van type maatregel, of niet?

S: Het is wel, ehm, het is wel nog deels generiek. Hij gaat wel nog bepalen je hebt muurisolatie nodig, maar of dat nou direct spouwmuurisolatie moet zijn of je gaat met PIR of PUR werken dat kan nog niet naar voren komen, dat zal een installateur moeten controleren wat allemaal mogelijk is. Ehm, alleen we weten wel met welke weerstandwaarden we willen werken. Dus daardoor kan je wel voor jezelf al een aantal producten eruit gooien. Van dat is niet mogelijk, dus je gaat kijken naar een aantal andere mogelijkheden kijken die daarbinnen vallen wat dan kan. En we hebben het gefaseerd in drie bundels. Dus de eerste bundel is het laaghangend fruit, tochtstripjes en slimme thermostaat. Die kan een installateur meenemen in zijn bus die dan de controle doet. Wat dat maakt helemaal niet uit voor zijn afmetingen of wat dan ook. Dus die kan hij alvast ophangen indien de woningeigenaar dat wenst. En daarna gaat hij dus de maten opnemen voor de isolatie en de zonnepanelen wat is allemaal mogelijk daarin. En dan komt daaruit wat uit en dan kan iemand daar hier ja op zeggen. En dan in de laatste fase gaan we kijken naar een warmtepomp. We willen wel dat, dat efficiënt gebeurt, vandaar de naam ook Efficiator en niet dat je eerst een warmtepomp doet en dan blijkt dat je een energiezuinige woning hebt en een veel te grote unit hebt staan die te veel energie verbruikt.

R: Oke, dus je kijkt naar passieve maatregelen en ook actieve, dus ook zonnepanelen.

S: Ja.

R: En dat doe je neem ik aan ook in een model?

S: Ja. Kijk uiteindelijk, een woning verbruikt geen energie. Dat doet een mens. Dat maakt het dus lastig voor de passieve maatregelen, zoals een slimme thermostaat. Als jij nooit je verwarming hebt aanstaan in je huis, zal je dus ook nooit wat gaan besparen met een slimme thermostaat. Dus dan moet je, je wordt gedwongen om naar een bandbreedte te gaan kijken en een aanname daarop te gaan doen en dat je situatie is. Het is alleen het gevaar dat jij jezelf niet rijk moet gaan rekenen dus je kan beter wat minder realistisch zijn, dus dat je wat van een negatiever scenario uitgaat dan overdreven positief. Want anders is dat nu misschien leuk, kan je veel verkopen. Maar uiteindelijk ga je daarmee veel gedoe mee krijgen want je bent mensen aan het misleiden.

R: Ja inderdaad. Oke en, waar haal jij allemaal rekening mee met zo'n analyse. Ik heb wat op papier gezet.

S: Ja.

R: Dit is wat ik uit de literatuur en als ik mensen spreek wat ik tegenkom, wat nou bepalend is voor je aanpak. Ehm, we hadden het net ook over woningeigenschappen, woningcorporaties of een private huurder. Dat hangt er natuurlijk af wat je wil en wat mogelijk is. Maar je aanpak is natuurlijk anders en waar je op stuurt.

S: Ja, die verschilt wel. Ehm, ja we werken ook met VVE's samen en doen we alleen scans mee en daarnaast doen we er niks mee. We weten, het duurt anderhalf voordat je een ja krijgt. Maar dan krijg je een ja op 1 onderdeel, maar daarvoor heb je wel 20 keer moeten presenteren. Dan is het voor ons economisch niet meer rendabel om langs te komen. Hoe graag we het ook willen, we willen natuurlijk iedereen helpen maar we moeten nu keuzes maken. De markt is nu groot genoeg omdat zelf te bepalen.

R: En wat voor andere dingen nemen jullie dan mee?

S: Wat ik bijvoorbeeld in dit lijstje mis, is gezinssamenstelling.

R: Ja.

S: En ik neem aan dat je met vormcomplexiteit, daar bedoel je de afmetingen van de woningen mee?

R: Ja.

S: Je kan er nog heel wat dieper in doorgaan maar dat is aan jou.

R: Wat nemen jullie dan mee als je naar dat lijstje kijkt?

S: Ehm, eigenschappen doen wij ook. Daar hebben we de keuze gemaakt voor woningeigenaren. Gebouweigenschappen ook. Ook bouwjaar, laten we daar ook oevervallen. Vormcomplexiteit ook, wat zijn de afmetingen. Wat bedoel je met oriëntatie?

R: Dat is de richting van de woning qua noordwest.

S: Oke, ja dat doen wij ook. Dus west west oost. Of west west zuid. Energy performance ook. Aanpak schaalgrootte project. Hier houden wij ook rekening mee, we werken zelf met batches van 10.000. Want je hebt altijd uitval, net als een mailing. Als jij 1000 wilt, dan ehm, dan doe je het goed als je 1 procent respons hebt. Daarom wil je ook met volumes werken, want een installateur vindt het niet leuk om voor 1 spouwmuur, maar die vindt het harstikkende leuk als hij er 10 op een rijtje heeft.

R: Oke, dat is het ding, zoals die aanpak en schaalgrootte. Tuurlijk wat je zegt, hoe meer woningen je doet in 1 keer, hoe goedkoper het wordt.

S: Ja dat is gewoon de wet van de grote getallen.

R: Alleen, dingen zoals, hoe pak je dat aan met zo'n tool. Zo'n koopwoning, ik kan zeggen Jantje wilt renoveren, en als je de hele straat doet kan het goedkoper. Maar goed, dan moet iedereen dat willen, dingen zoals zonnepanelen ook. Ook een warmtepomp, die dingen op een grootschalige doen. Hoe pak je dat aan?

S: Kijk je hebt altijd een keerzijde, ehm. Je hebt altijd een keerzijde, natuurlijk wil jij het liefst 1 straat in één keer doen. Dan kun je de daken ook doortrekken enzo. Dat is een utopie, dat zal nooit gebeuren. Daarvoor moet je bij de nieuwbouw zijn. Maar een installateur kan dus wel groter inkopen, daardoor kan hij wat meer volume verlaging krijgen. En daardoor kan hij dus wel wat marktconforme prijzen neerleggen. Dus daarmee zakt de woningeigenaar ook iets in de prijs.

R: Ja precies.

S: en uiteindelijk is, moet het een win win situatie zijn voor alle stakeholders die erbij betrokken zijn. Dus dat zijn ook grote partners zoals Stedin en een bank. Dat is ook voor de installateur, helemaal voor de woningeigenaar hij moet gelukkig zijn, en wij zijn er ook en moeten ook een boterham verdienen.

R: Inderdaad.

S: omdat je dus met schaal werkt, kan je dus kijken wat nou een eerlijke verdeling is van de opbrengsten en hoe je dat doet.

R: Oke, en als je dan kijkt naar zoals uiterlijk en esthetiek van de woning daar heb je ook mee te maken. Als je bijvoorbeeld van buitenaf gaat isoleren en dingen erop gaan plakken. Dat kan je wel aanbieden maar dat.

S: Nee klopt, wij doen geen ledverlichting, want licht is een persoonlijke voorkeur. Dus het heeft geen zin om zelf peertjes mee te nemen ook al zijn die de beste. Als de meneer of mevrouw het niet mooi vindt, dan gaan wij het toch niet ophangen. Dus het is zonde van hun en onze tijd. Wat wij wel doen is advies, van hé hier heb je een link naar een leverancier van led-lampjes die doen aan thuisbezorgingen doe dit dat gaat je geld besparen.

R: Oke.

S: Maar wij blijven ervan af. Wij gaan geen lampjes erin draaien. Dan heb je, licht is wat gevoeliger, dan heb je zonnepanelen die zijn ook gevoelig. Mensen vinden die of niet mooi, of moet een andere kleur zijn. Dan kom je wat verder. Maar als je kijkt naar isolatiemateriaal, dat maakt niet uit. Dat maakt mensen niet uit wat er in de spouw komt.
Je wilt zover mogelijk van het aanpassen van de woning afblijven, wij willen ook niet dat onze installateurs met hamers dingen gaan openbreken, dan heb je altijd de poppen wel aan het dansen. Ehm, dus je gaat kijken hoe je nou een oplossing kan verzinnen die daar geen last van heeft om nog steeds hetzelfde resultaat kan garanderen.

R: Oke, je zou het wel kunnen adviseren, stel het is geen probleem.

S: Tuurlijk, zonnepanelen adviseren wij ook. En als je iemand het wil is dat prima. En als iemand de zonnepanelen die wij leveren lelijk vinden, ja dan moeten we daar een substituut voor zoeken of een moeten we daar meerdere keuzes in hebben. Maar dat is ook iets wat wij ook moeten ervaren tijdens het proces. Uiteindelijk willen wij gaan werken met volledige zonnepanelen daken zeg maar.

R: Ja helemaal geïntegreerd.

S: Ja, maar dat moet iemand ook maar willen en mooi vinden. Maar daar kan je wel veel meer mee bereiken. Maar goed dat is nog een stukje bewustwording van de consument ook. En dat is gewoon kopieergedrag wat zich moet gaan ontwikkelen.

R: Ja inderdaad. En dingen zoals goed, kosten is natuurlijk overduidelijk.

S: ja dat is de allerbelangrijkste drijfveer. Ook als je de onderzoeken leest. Andere mensen beweren wel eens dat duurzaamheid echt de belangrijkste motivator is. Maar mensen zullen eerlijk antwoord geven, want uiteindelijk gaat het om geld. Ze zullen eerst zeggen duurzaamheid vind ik belangrijk omdat het van hun verlangd wordt. Maar uiteindelijk gaat het om de besparing. Kunnen ze nog stiekem naar Kroatië op vakantie of Griekenland of vliegen. Maar dat schiet natuurlijk het doel voorbij maar daar moeten we maar een andere startup voor hebben die dat goed kan doen.

R: Ja precies. Kunnen bewoners ook dat aangeven of zoiets? Want als je renoveert, mensen renoveren vaak of het is nodig, puur omdat het gebouw slecht is of aangepast moet worden en dan energie erbij te pakken. Of ze doen het omdat ze hun energierekening willen verlagen. Maar duurzaamheid, ik weet niet of dat bij woningen vaak een driver is.

S: Nee, maar wat wel vaak een driver is een investering in je eigen wat al van jou is. We zijn nu in gesprek met de NWWI. Ehm, en we hebben met hun een gesprek gehad. En ze zeiden dat de woning wel degelijk wordt aangetast door een duurzame maatregelen die te treffen, want als jij het niet doet, dan moet de volgende bewoner het wel doen. Iemand is het klosje zeg maar, daardoor kan je wel je waarde omhoog brengen. Alleen het probleem is dat makelaars dan lak gaan hebben en het gewoon niet willen meenemen. Die vertikken dat om dit te vertellen. Maar goed dit is een proces wat meer op gang moet worden gezet. En als je dan kijkt naar hypotheek garantie kijkt die maken zich daar ook weer hard voor. Makelaars worden nu ook verplicht om een nieuw taxatierapport, ik weet niet of je die hebt gezien die is nu sinds een 4 maanden terug aangepast. Dus daarmee hebben ze dus wat meer aandacht gegeven aan duurzaamheid. Dus nu moeten makelaars er wel wat meer over gaan vertellen. Daardoor zie je ook wel dat er, dat 5 procent van alle woningen die verkocht worden nu een stukje duurzaamheid erbij krijgen. En terwijl dat 2 jaar geleden 1,25 procent was. Dus dat zit wel in de lift.

R: Dat gaat tijd kosten voordat dat.

S: Ja tuurlijk, maar de overheid is er druk mee bezig. In 2030 gaan we van het gas, dus dat betekent dat we naar Poetin moeten gaan voor ons gas. Nu zijn onze verstandhouding daarin niet heel lekker. Maar goed dat is een andere discussie.

R: Ja inderdaad, en als je naar dat advies kijkt wat jullie genereren. Dat doen jullie dus op basis van die input. En wat zijn harde, jullie werken met een soort van base case. Bijvoorbeeld te zeggen de woningen hebben isolatiewaarde van X.

S: Ja, ja.

R: en dan zeggen jullie oké, we trekken dit naar Y. En daaruit volgt dus automatisch een besparing van Y.

S: Ja.

R: Met plus een soort van pakketenmaatregelen denk ik?

S: Ja dan komt er een, ehm, daar rekent die uit hoeveel vierkante meters, hoeveel uur arbeid daarin zit en wat de materiaalkosten van zijn. En daar komt dus een resultaat uit

R: Oke en zoals je zei daar komt dus niet uit of het materiaal nou PUR of PIR of glaswol, steenwol wordt.

S: Nee dat is aan de installateur hoe hij ermee omgaat. Wij zullen dat controleren, dus als hij beweert met een weerstandwaarde van 5 werkt, terwijl dat 3 is dan gaan wij hem op de vingers tikken want dan is hij dus aan het liegen. En als hij 5 heeft is het aan hem om een oplossing te zoeken die hierbij past. Natuurlijk kunnen wij iets adviseren aan de installateur. Natuurlijk moet je dit een paar keer doen en dan gaan ze anders kijken naar de woning. Over het algemeen zijn ze heel erg stug. Ze werken met 1 product of 1 leverancier dat doen ze altijd en dat gaat goed en dan moeten ze ineens iets anders doen.

R: En wat zijn zeg maar harde randvoorwaarden, waarvan je al dingen kan afvinken in dat advies? Stel je voor het wordt een woning uit 1945 en het is ontzettend slecht, label G bijvoorbeeld. En je wilt naar A, maar dat kost ontzetten veel geld om die woning tot dat niveau te krijgen. Dan lijkt mij het logisch dat je niet alles kan hebben want dan moet je al het geld op de wereld hebben om die woning te renoveren.

S: Nee kijk, dan ga je dus praten over financiële constructies die je hierbij toepasbaar zijn. Het punt is als je het doet, krijg je wel een verhoogde woningwaarde dus jouw woning wordt meer waard. Dus je hebt je investering, die gooi je niet helemaal weg. En daarnaast gaat je energierekening zover naar beneden dat je dat op een gegeven moment ook terugverdient. Dus als je die uitkomst laat zin in jaren en waarde dan kan je op die manier overtuigen. En ja het is mogelijk om ze alles aan te bieden, alleen of dat kan is inderdaad weer aan de installateur. Dus het kan best zijn dat onze tool zegt, hé je moet je muren, vloer, dak, zonnepanelen, warmtepomp nemen en een aantal passieve maatregelen doen. Dan kan blijken dat het helemaal niet mogelijk is dat, dat bijvoorbeeld een vloer is al geïsoleerd of daar zit rot in of weet ik veel wat. Dan praat je dus over een hele andere gratie en dan moeten wij dus wel in gesprek gaan met de consument, van hé ehm, wij hebben dit gebaseerd op deze informatie er mist informatie dus, we moeten even kijken naar een andere oplossing.

R: En zal er altijd een soort van optimale strategie zijn of maatregelpakket zijn? Als je van niveau X naar Y wilt dan kan dus op verschillende manieren. Dat zie je ook in de praktijk. Dan zie je dat bij bijna identieke gebouwtypen en bouwjaren toch veel verschillende maatregelen en strategieën worden gebruikt. Waar hangt dat nou van af?

S: Dat kan, maar nu ben ik aan het gokken. Dus ik weet niet specifiek een antwoord daarop. Maar dat kan komen omdat een installateur liever met een ander materiaal werkt of te koppig is om dit te doen. Een mooi voorbeeld om van ons te nemen, Richard een compagnon, heeft zijn woning verduurzaamd. Dit heeft hij met een onderaannemer gedaan, hij zegt ik wil driedubbel glas. De installateur zegt we doen dubbel, maar ik wil driedubbel, de installateur zegt dat driedubbel is goedkoper. Ik heb een subsidie en nu zijn ze even duur zegt hij, maar de installateur zegt, maar dan moet ik dikkere balken kopen. Maar je pakt wel 15 euro meer op die balken. Dus het gaat meer om de mindset ook af en toe van de installateur dat ze niet willen afwijken van hetgeen wat ze aan het doen zijn. Het kan de reden zijn dat ze kiezen om het niet te doen omdat het niet in hun vakgebied en expertise valt en een andere mogelijkheid is dat, je had het over volledig hetzelfde gebouw he?

R: Ja, bijna hetzelfde.

S: want als het in dezelfde wijk is door dezelfde architect dan zou het identiek moeten zijn.

R: Verschillende wijken ging het om.

S: als het dezelfde bouw is met dezelfde architect dan zou het niet de reden zijn dat de maatregel anders is.

R: Zijn er andere harde randvoorwaarden die je op basis van die basisgegevens al dingen kan uitsluiten? Of is het.

S: Je weet bijvoorbeeld vanaf 1965 uit mijn hoofd, dat weet ik niet zeker, mocht er niet meer gebouwd worden met enkelglas. Dus kan je altijd enkelglas eruit gooien. Dus vanuit de bouwbesluiten kan je kijken, dit is de isolatiewaarden, het is op deze manier gebouwd, dus daarmee kan je dingen elimineren. Maar wat weer een 1930 woning, ja ik kan je er goud, 100 euro op inzetten dat een installateur is langs geweest en die iets anders heeft gedaan. Er kan een andere ketel in zitten dan vroeger, bijvoorbeeld een HR+ ketel, of dat hij een uitbouw heeft gedaan. Dus dat maakt het lastig. Dus je wil eigenlijk een high level plaatje geven in eerste instantie met alleen de eerste resultaten en dan moet je daarna de weg naar die resultaten vinden.

R: oké.

S: en dat vergt dus een creatief denkvermogen van zowel ons als de installateurs want uiteindelijk moeten zij het gaan doen. Dus wij moeten ook geen bureaucratisch verhaal gaan geven, van je moet met PUR werken want dat werkt het best, als het gewoon niet kan dan kan het gewoon niet.

R: Dat is gewoon maatwerk.

S: en daar zal je, ja, misschien over 20 jaar wel maar dan moet gewoon een goede AI hebben, die als jij door je huis loopt en het filmt maar dat zie ik nu nog niet gebeuren. Nu heb ik nog geen technologische producten gezien die daarbij kunnen helpen. Maar dat komt wel meer aan gang.
R: Dus jullie kijken eigenlijk puur naar het bouwjaar denk ik dan en op basis van bouwjaar en bouwbesluit, dan heet het deze waarde en dan is dit mogelijk.

S: Ja precies en dan heb je allerlei natuurkundige formules, die weet ik zo niet uit mijn hoofd, die je daarvoor gebruikt.

R: Ja dat is allemaal volgens de NEN en andere handboeken hoe je dat berekend.

S: Ja en uiteindelijk houden wij gewoon bij, wat is, wij willen dat wel efficiënt doen. Je kan nu bijvoorbeeld zonnepanelen nemen van 330 watt/piek. Maar als die dingen 10.000 euro kosten per paneel en je hebt een zonnepaneel van 300 watt/piek en die kosten heel wat minder dan kan je dat efficiënter zijn om die te kopen. Maar dat is een kwestie van je inkoop strategisch regelen.

R: Oké. En is überhaupt woningtype van belang, pak je een vrijstaande woning anders aan dan een rijtjeswoning?

S: Ehm, de aanpak zal ongeveer gelijk zijn, alleen wat anders is, is dat je bij een rijtjeswoning heb je aan 2 kanten verlies en bij een vrijstaande woning 4. Als je alleen kijkt naar de muur. Daar kijken we wel naar woningtypen, een appartement kan helemaal ingebouwd zijn en heeft dan maar 2 zijdes. En, ehm, dat moet je dus wel kijken, wat is nou zinvol. Er zijn wel heel veel onderzoeken gedaan en daardoor heb je een hele grote bandbreedte en dat maakt het wat lastiger. Maar er zijn wel formules voor te bedenken.

R: En nog een dingetje is denken jullie ook, stel je hebt een woning, en er komt over 5 jaar een warmtenet, dan hoef je die woning niet superhard te isoleren. Kijk je ook naar dat soort aspecten, zoals no-regret maatregelen?

S: we willen absoluut geen troep verkopen. Ehm, wij willen liever ook geen hybride-warmtepomp aanbieden en dat is puur omdat bij wijzelf geloven niet dat het slim is om een hybride-warmtepomp aan te bieden omdat het niet naar behoren presteert.

Dus je kan veel beter een wat grotere doen, maar als de consument aangeeft ik wil dit, ik wil hiermee ervaring hebben dan zit het daar dus wel in. Wij zeggen wel, neem een grotere warmtepomp en daardoor hoef je dus niet terug te vallen op het gasnet en kan je dus je gas eruit halen en scheelt het dus ongeveer 257 euro per jaar. Voor je aansluiting of. En wij worden ook wel benaderd door grote partijen van hé, deze wijk gaat van het gas af. Die krijgen een warmtenet, hoe gaan jullie daarmee om? Wij zijn daarmee wel mee bezig. Alleen dat zijn wat langdurige plannen, wij willen het op een gegeven moment wel opnemen als de mogelijkheid er is. Maar als het nu vooral beleid schrijven is dan gaan we er nog niet mee bemoeien. Maar daarom focussen wij ons in eerste instantie op, ehm, het isoleren, dan ga jij je verbruik naar beneden halen. En nu gaan we een project doen in een woonwijk die all-electrict gaat worden. Dat er geen warmtenet, geïnstalleerd kan worden.

R: oké, dus als je kijkt naar jullie afwegingskader wat jullie gebruiken om van niveau X naar Y te gaan. Dan is het kortgezegd gebaseerd op het bouwbesluit, het type woning.

S: ook woningoppervlak, in ieder geval alle afmetingen. Je wilt weten wat de afmetingen zijn van de vloer, het dak de muur en je wilt weten wat zit erin, wat zijn de waardes daarvan. En dat, dat is, wij hebben het zeg maar zo gedaan, bij ons is alles modulair. Dus je kan je, een muur is een aparte maatregelen, een muur kan je eruit halen en een nieuwe erin zetten. Theoretisch gezien. En zo kan jij je hele berekening doorlaten muteren. Uiteindelijk heeft het allemaal invloed op elkaar. Als jij een waterbak hebt met één groot gat en vier kleine gaatjes. En dan die kleine gaatjes dichtmaken, dat heeft effect op elkaar. Als je die grote dicht dan gaat er net wat meer water uit die andere vier stromen. Daardoor houden we wel rekening dat als je muurisolatie doet en vloerisolatie die je los hebt, die klopt niet. Dan moet je een percentage daarmee vermenigvuldigen. Het is dus niet 1 en 1 is 2, maar 1 en 1 is 1,9.

R: Maar gegevens zoals muuroppervlak, waar halen jullie dat uit?

S: uit het kadaster en tekeningen. Uit het kadaster weet je wel het woonoppervlak, we hebben een andere partij die weet hoeveel verdiepingen er in een woning zit. Bijvoorbeeld Funda weet deze informatie ook. Dan weet je hoeveel verdiepingen erin zitten en dan kan je dus op basis daarvan een berekening loslaten, van hé, dit zijn de afmetingen van de muren. Maar daarom moet een installateur wel weer metingen doen.

R: En glasoppervlak?

S: Glasoppervlak ook. Daarvoor heb je vuistregels. Architecten werken ook met vuistregels hiervoor, volgens mij wil je niet meer dan 40 procent van je muur aan ruit hebben omdat je dan te veel lichtinval hebt. Ik kan je één ding vertellen dat is de grootste uitdaging in heel de vastgoedsector is dat gewoon de informatie en de online informatie heel erg minimaal is. En dat zorgt ervoor dat innovatieve partijen die met big-data willen werken, dat is gewoon lastig omdat er gewoon te weinig beschikbaar is en heel veel klopt ook niet. Funda is daarmee begonnen om dat goed te krijgen, maarja die hebben nog niet elke woning verkocht in Nederland.

R: Dat is ook de crux, hoe kan je met zo min mogelijk informatie zo veel mogelijk bieden.

S: Daarom willen wij wat high-level houden en daarna gaandeweg onze eigen modellen steeds beter en nauwkeuriger krijgen. Omdat als je meerdere woningen hebt gedaan dan kan je wel de relevantie bepalen. Maar dat zal dan een fulltime job zijn om te kijken naar de data.

R: Oke, want hoe ik te werk ga is op basis van open data uit het GIS-tooltje en de kern daarin zijn energie labels, gebouwtypen en bouwjaren. Het is wel zo, energie labels zeggen niet alles.

S: Nee want heel veel is nu geschat. Ik vind het wel goed dat de overheid iets heeft gedaan in plaats van niks. Maar het is geschat want er klopt nog niks van.

R: Heel veel zijn voorlopig inderdaad. Je hebt wel 3,5 miljoen woningen waarvan de energie label geregistreerd is. Dan komt een energieadviseur komt langs en checkt, he matched dit.

S: het is wel heel erg fraudegevoelig want je moet een foto maken van je cv-ketel en dan kan je gewoon naar je buurman. Ik heb ook problemen gehoord van mensen die hadden een probleem met het aangeven van de energielabel die hadden de cv-ketel eruit gehaald want die wilden van het gas af, maar die moesten een foto hebben van de cv-ketel. En dat hadden ze niet. Toen zijn ze naar de buren gegaan, daar een foto gemaakt en toen was het goed.

R: Ja er komt niet daadwerkelijk iemand langs.

S: Ja, maar goed.

R: Mijn tool moet werken met verschillende scenario's, zoals ik wil van label C naar A voor het minste geld, of laagste energierekening of CO2.

S: Dat ligt er dus aan wat de wijk wil, willen ze echt NOM-woningen of heel veel CO2 besparen, dan moeten ze allemaal over produceren bij wijze van.

R: Ja dat is het inderdaad. Je moet met scenario's kunnen werken.

S: We hebben dat ook gedaan maar daar zijn we vanaf gestapt. We geven er wel inzicht in maar alleen we zeggen alleen kosten, punt.

R: Ja precies.

S: maar het ligt eraan voor wie je het doet. Ehm, voor woningcorporaties kan ik wat bedenken dat die wat andere redenen heeft om wat te doen, maar stiekem gaat, het kost veel geld, dus dat wil je eigenlijk wel kostentechnisch efficiënt doen en de rest is allemaal bijzaak wat mooi meegenomen is. Maar ik snap het wel, je moet het ook die manier kunnen vertellen. Kijk je daar ook naar persoonlijke karaktereigenschappen, bijvoorbeeld in een wijk die wat welvarender is zie je over het algemeen meer op de vvd wordt gestemd, wat meer levensgenieters zijn, wat minder milieubewust. Natuurlijk geldt dat niet voor iedereen maar dan kan je wel wat een betere psychologische analyse erin verwerken.

R: Ja, kijk, is er een relatie tussen het energieverbruik en GroenLinks stemmers. Die zijn misschien energiebewuster dan VVD stemmers. Ja, ik neem het niet mee. Omdat het gewoon ja..

S: Er zijn wel partijen die hier werk van hebben gemaakt.

R: Ja ik benoem het wel, het kan van invloed zijn, maar het zijn niet de eerste dingen waar naar je kijkt om het energieverbruik te bepalen.

S: Het telt wel met je strategiebepaling maar puur rationeel gezien heeft het geen invloed wat nou de beste oplossing is.

R: Nee precies, maar het is wel iets wat kan spelen. Stel je voor het is een wijk met mensen die in de uitkering zitten dan.

S: Ja dat kan maar die hebben geen geld te makken, dus dan kan je al nadenken van het moet allemaal zo goedkoop mogelijk. Dus dan ga je kijken naar goedkope investeringen met snelle terugverdientijden. 7 jaar dat vinden mensen max. Want over het algemeen woont de gemiddelde Nederlander ook 7,1 jaar in hun woning voordat hij of zij verhuist. Klopt niet helemaal want in je studietijd verhuis je wat meer en als je kinderen hebt blijf je over het algemeen wat langer in dezelfde woning. Of je moet dan de gemeente benaderen of zij een fonds willen opstarten, dat kan op zich wel. Maar dan moet je weer door een hele hoop bureaucratische stappen heen. Maar dan ben je dus aan het lobbyen voor geld, dat kan ook. Maar goed. Maar op zich ik vind je aanpak logisch. Maar waar loop je nu nog tegenaan?

R: Waar ik nu tegenaanloop is meer model technisch eigenlijk. Wat voor platform kan het, ik denk dat het afwegingskader wel nu inzichtelijk.

S: Naar mijn inzicht heb je dat nu wel goed. De theorie kan veel verder gaan, maar dat is niet.

R: ja dat is het probleem met onderzoek.

S: Ja uiteindelijk kan je ook opmeten wat de invloeden zijn van alle schroeven die toentertijd zijn gebruikt.

R: Ja precies. Nee dus dat heb ik nu voor ogen. Hoe dat nu zit en waar dat van afhangt. Wat er bij een renovatieproject belangrijk is. Maar kort gezegd, wat ik merk of hoor is dat het niet heel rationeel gedaan. Bij een renovatieproject, doe mij een woning, ik heb een spouwmuur, doen we PUR erin, waarom? Geen idee, het dak daar zit dit in. Doe maar dat. Dat is beetje het probleem, want ik dacht er zal vast wel overal een reden zijn, maar dat is niet zo.

S: Het is meer psychologisch dan technisch. Technisch gezien kan alles, alleen. Je kan overal een muur inzitten of overal een nieuwe schil omheen gooien, maar een nieuwe schil is echt achterlijk duur. Dat wil je niet, dat wil je het liefst vermijden. Maar een bewoner wil je ook niet zijn vloeroppervlak opsnoepen omdat je 10 cm isolatiemateriaal tegen de muur wilt plakken. En dat zijn allemaal weer obstakels die het gewoon lastig maken, er zal ook nooit één oplossing zijn. Alleen je kan wel, ehm, mogelijkheden naast elkaar leggen. Van dit is wat we willen doen, dit willen we behalen, dat kan op deze manier of deze manier. Dat zijn de enige manieren, ja of nee. Maar dat is meer ons commerciële perspectief. En ja uiteindelijk iedereen mee kunnen krijgen, het is nu heel lastig om mensen te kunnen overtuigen om een wijk in één keer aan te kunnen pakken. De overheid probeert doormiddel van warmtenetten en daar 100 procent subsidie op te geven. En dat je dan meedoet. Nou ik wil nooit van mijn leven een warmtenet. Ik zit zelf op stadsverwarming, ik betaal achterlijk veel. Ik een warmwater aansluiting, een gasaansluiting en elektriciteitsaansluiting, dus ik betaal 200 euro per jaar om te koken. Maar ik kook bijna nooit. Dus ik verbruik 10 kuub, en daar betaal ik 200 euro voor. Ik wil dat ding eruit hebben, het is een huurhuis, dat kan niet en is moeilijk dus ik wil dat gewoon niet. Ehm, plus dat je altijd afhankelijk zal zijn. Dus we gaan er heel veel problemen mee krijgen, heel veel weerstand krijgen. Ook al doen ze het gratis. Het is wel iets wat we moeten doen. Want het is een en oplossing, daar gaan mensen buitenvallen. Hoe je dat erdoor heen drukt, ik weet dat antwoord daarop ook niet. Alleen wij denken dat je dat het beste kan doen door heel duidelijk, eenvoudig en transparant kosten-baten analyse te laten zien die op maat gemaakt is.

R: ik denk dat dat soort dingen inderdaad nodig zijn ja om zover te komen. Want je merkt dat iedereen zich nu gaat afvragen hoe je dat gaat doen. Ik zie heel veel onderzoeken en heel veel manieren, modellen en methodes, maar het is allemaal nog steeds.

S: Het is heel veel praten nu, alleen je kan hier alleen achter komen als je er mee bezig bent. En je moet tegen al deze vraagstukken aanlopen en ik vind eigenlijk dat je een landelijk draagvlak moet hebben om allemaal van dit soort initiatieven. Dat we dit met z'n gaan delen en met z'n allen sneller kunnen groeien want het heeft geen zin wat wij hier nu aan het uitvinden zijn, in Amsterdam zijn ze nu ook weer het wiel opnieuw aan het uitvinden en ik weet nog een paar andere bedrijven die het nu ook aan het doen zijn, maarja.

R: Ja precies, enerzijds hebben we niet heel veel tijd daarvoor.

S: we gaan 2050 ook niet halen, het is fysiek onmogelijk nu. Tenzij we nu in één keer heel veel mbo'ers krijgen die gaan afstuderen en die voor installatietechniek gaan. We hebben nu te weinig handjes ervoor en die moeten ook beter opgeleid worden.

R: ja klopt we hebben te weinig capaciteit om dit te realiseren in die tijd. En ook de kosten, Aedes zei laatst dat het 103 miljard euro gaat kosten om alleen sociale huur te doen.

S: Ik heb met Andy van de Dobbelsteen nu ook contact mee gehad en die wist voor 70.000 euro een woning te vernommen. Ze zeiden dat het doormiddel van automatisering 50.000 euro kan gaan kosten, wij denken dit met 35.000 te kunnen doen. Ehm, maarja het gaat gewoon een hele hoop geld kosten. We hebben 7,6 miljoen woningen in Nederland, op basis van de getallen van Dobbelsteen, keer 50.000, ja weet je het is zo groot en we moeten niet gaan zeiken en ons best gaan doen om 1 procent van de markt of 10 procent van de markt te beheren want je kan het niet eens. Want fysiek zal je ten alle tijden te klein zijn om zoveel woningen te kunnen bedienen. Wij gaan ook niet even 400.000 woningen even upgraden.

R: Dat zou leuk zijn.

S: Ja dat zou ik geweldig vinden want dan zit ik over 5 jaar op het strand op mijn eigen eiland. Nu is het een obstakel om de goeie jongens te vinden die snappen, die niet denken wat jij ook in je onderzoek aangeeft, van deze muur doe we altijd zo. Doen we het weer. Ik weet niet hoe die vloer moet, laten we lekker liggen joh. Dat is gewoon een kwestie van mindset.

R: Precies.

S: Maar goed, kan ik je nog ergens mee helpen?

R: Nee ik denk dat het ongeveer zo wel goed is.

Informed consent form

Title research or acronym: Optimizing the large-scale renovation strategy

I declare to be informed about the nature, method and purpose of the investigation. I voluntarily agree to take part in this study. I keep the right to terminate my participation in this study without giving a reason at any time.

My responses may be used solely for the purposes of this study. In its publications, they may *(please tick one of the options):*

O be cited with my name or function revealed
O be cited anonymously, thus without identifying context
O only used as information source

During the course of the interview I keep the right to restrict the use of (some of) my answers further than indicated above.

Name participant: Sonder Horbevig

Date: 4-7-2018 Signature participant:

I declare to fully adhere to the above.

Name researcher: Jarich (Rick) Dijkstra

Date: 04-07-2018 Signature researcher:

Figure XIII.1 Informed consent