MASTER

Exploring the feasibility of energy neutrality in existing office buildings with current instruments

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EXPLORING THE FEASIBILITY OF ENERGY NEUTARLITY IN EXISTING OFFICE BUILDINGS WITH CURRENT INSTRUMENTS

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MANAGEMENT SUMMARY - ENGLISH

The climate changes and more and more uncertainty exists concerning the energy supply. The discussion is no longer about the need to contemplate the future of energy supplies but about the way we can meet the future energy demand in a sustainable way. Given the massive growth in new construction in economies in transition, and the inefficiencies of existing building stock worldwide, if nothing is done, greenhouse gas emissions from buildings will more than double in the next 20 years (UNEP SBCI & Sustainable United Nations, 2009). Besides the greenhouse gas emissions, energy, mostly from fossil sources, will greatly increase in price in the future because of the looming shortage of (affordable) fossil energy in conjunction with the supply. As for most developed countries, the energy system in the Netherlands is largely driven by the combustion of fossil fuels. The built environment accounts for approximately 35% of the total Dutch energy consumption. More than half of this part is used in commercial buildings such as offices (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012). The life-cycle approach reveals that over 80 percent of greenhouse gas emissions take place during the operational phase of a buildings when energy is used for heating, cooling, ventilation, lighting, appliances, and other applications. Energy neutral- buildings and renovating is desperately needed to keep the buildings affordable (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012).

This problem statement shows that the current fossil energy use from buildings and in specific, office buildings needs to be lowered or compensated by green (renewable) energy sources to lower the greenhouse gas emission and the prevention of depletion of fossil sources. Despite impressive technical innovations it is still not yet managed in the Netherlands and elsewhere in Europe to make existing buildings on a large scale energy neutral (GEN, Idema, and de Koning, 2014). This raises the question if it is possible to make existing office buildings energy neutral and if so, how? This research looks into this problem. The main research question is stated as *'what is the feasibility of the energy neutrality in existing office buildings with current instruments?'* In order to answer the main research question several sub research questions are proposed as:

RQ1	What is energy neutrality and when is it reached?
RQ2	What kind of energy improvement tools are available on the market and can be used to make a building energy neutral?
RQ2.1	What kind of energy improvement techniques are available for building specific optimization?
RQ2.2	What kind of sustainable energy generation techniques are available for on-site and off-site generation?
RQ3	What are the limitations regarding energy reduction based on energy efficiency and indoor climate requirements?
RQ4	How can the tools gathered from sub question 2 and 3 be used, so that it is usable for modelling?
RQ5	How can the usable tools be combined so that a model can be made in order to simulate the energy usage of an existing building?

In order to answer the main research question and the sub questions, a literature review is performed to gain insight in the different translations of the concept of Zero Energy Buildings and expert interviews are held to gain a practical view on the concept of Zero Energy Buildings. These two methods provided an answer to the first and third sub research question and can be found in chapter 3. The second step in the research was creating a dynamic model which showed the interrelationship between the different technologies for making buildings energy neutral and gain insight into their dynamic behaviour by using the software program Vensim.

The research gave answer to the above stated research questions, the main findings are explained next. Energy neutrality is explained as *'a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources from on-site supplies and if necessary off-site supplies'*. This means that neutrality is reached when there is 0 kWh fossil electricity use and 0 m^3 fossil gas use over a year. By making a model of the available instruments and the relationship between the techniques a case study was used to test if it is possible to reach neutrality with an existing office building. The case study showed that is possible for an office building to reach neutrality, which answers the main research question. In the case of the case study, neutrality is reached from step 4 where off-site generation is needed to reach neutrality. The case study showed that in some (or many) cases it will not be possible due to the on-site situation to reach neutrality within the building site. If that is the case, then off-site generation is needed to reach neutrality or even off-site supply. The model showed that it is possible to connect a building to off-site generation and reach neutrality. This research showed a bottom-up approach for making existing office buildings first, a small scale energy neutral.

A next step for further research can be to connect more buildings and lower the overall investment cost of the off-site generation techniques. Which creates an answer to another problem statement which was that it is still not possible to make buildings on a large scale energy neutral. This method showed that is possible to do just that.

This model can be used in practice for companies and in specific in this case for Heijmans as a tool which can be used for clients to convince them to invest in neutrality. Heijmans can use the tool by inserting their clients' buildings and see what needs to be done to reach energy neutrality. With this measure package list per client Heijmans can approach their clients and see whether or not they are interested in making their building energy neutral. But also show that by working with other building owners, the investment of the more expensive technologies lowers significant. This model can function as basis for convincing their clients that it is possible to reach neutrality. This model takes minimum time and capacity to insert a building and show the results.

MANAGEMENT SUMMARY - DUTCH

Het klimaat verandert en er bestaat steeds meer onzekerheid over de energievoorziening. De discussie gaat niet meer over de noodzaak om in de toekomst ander duurzame energievoorziening te overwegen, maar over de manier waarop we kunnen voldoen aan de toekomstige vraag naar energie op een duurzame manier. Gezien de enorme groei in de nieuwbouw in economieën in transitie en de inefficiëntie van de bestaande gebouwenvoorraad in de wereld, betekend dit concreet dat als er niets wordt gedaan de broeikasgasemissies van gebouwen zal gaan verdubbelen in de komende 20 jaar (UNEP SBCI & Sustainable Verenigde Naties, 2009). Naast de uitstoot van broeikasgassen ontstaat er nog een probleem. Energie voornamelijk uit fossiele bronnen zal sterk in prijs stijgen in de toekomst, dit als gevolg van de dreigende tekort aan (betaalbare) fossiele energie. Zoals voor de meeste ontwikkelde landen, is het energiesysteem in Nederland voornamelijk gedreven door de verbranding van fossiele brandstoffen. De gebouwde omgeving is goed voor ongeveer 35% van het totale Nederlandse energieverbruik. Meer dan de helft van dit deel wordt gebruikt in commerciële gebouwen zoals kantoren (Agentschap NL, Infoblad energieneutrale Scholen en kantoren, 2012). Uit de levens cyclus benadering blijkt dat meer dan 80 procent van de uitstoot van broeikasgassen plaats vindt tijdens de operationele fase van de gebouwen wanneer energie wordt gebruikt voor verwarming, koeling, ventilatie, verlichting, apparaten, en andere toepassingen. Energie neutrale gebouwen en renovatie van bestaande panden is hard nodig om de gebouwen betaalbaar te houden (Agentschap NL, Infoblad energieneutrale Scholen en kantoren, 2012).

Dit probleem benadrukt dat het huidige fossiele energieverbruik van gebouwen, en in specifieke kantoorgebouwen verlaagd moet worden. Een andere manier is het gebruik van groene (hernieuwbare) energiebronnen om de uitstoot van broeikasgassen te verlagen en om het dreigende tekort aan fossiele bronnen te voorkomen. Ondanks technische innovaties is het nog steeds niet mogelijk in Nederland en zelfs in Europa om bestaande gebouwen op grote schaal energie neutraal te maken (GEN, Idema, en de Koning, 2014). Dit roept de vraag op of het mogelijk is om de bestaande gebouwen op grote schaal energie neutraal te maken en zo ja, hoe? Dit onderzoek kijkt naar dit probleem. De centrale onderzoeksvraag is geformuleerd als *'wat is de haalbaarheid van energie-neutraliteit in de bestaande kantoorgebouwen met de huidige instrumenten?'*. Om de centrale onderzoeksvraag te beantwoorden zijn de volgende sub onderzoeksvragen opgesteld:

RQ1	Wat is energieneutraliteit en wanneer is neutraliteit bereikt?
RQ2	Wat voor verschillende energieverbeteringstechnieken zijn beschikbaar op de markt en kunnen gebruikt worden om een gebouw energie neutraal te maken?
RQ2.1	Wat voor soort energieverbeteringstechnieken zijn er beschikbaar voor gebouw specifieke optimalisatie?
RQ2.2	Welke duurzame energieopwekkingstechnieken zijn beschikbaar voor op het gebouw terrein en buiten het gebouwterrein?
RQ3	Wat zijn de limieten voor kantoorgebouwen op basis van energie efficiëntie en het binnenklimaat?
RQ4	Hoe kan de informatie, verzameld in vraag 2 en 3 worden gebruikt zodat het bruikbaar is voor het modelleren?

RQ5 Hoe kunnen de bruikbare instrumenten worden gecombineerd, zodat een model kan worden gemaakt om het energieverbruik van een bestaand gebouw te simuleren?

Om de centrale onderzoeksvraag en de sub-vragen te beantwoorden, is een literatuurstudie uitgevoerd om inzicht te verkrijgen in de verschillende vertalingen van het begrip Zero Energy Buildings. Daarnaast worden er expertinterviews gebruikt voor een praktische weergave van Zero Energy Buildings. Deze twee methoden geven antwoord op de eerste en derde sub onderzoeksvraag (zie hoofdstuk 3). De tweede stap in het onderzoek was het creëren van een dynamisch model om de samenhang en onderlinge relatie van de technieken te modelleren en inzicht te vergaren in het gedrag van het systeem met behulp van het software pakket Vensim.

Het onderzoek geeft antwoord op de bovengenoemde onderzoeksvragen en de belangrijkste bevindingen worden verder uitgelegd. Energieneutraliteit is in dit onderzoek uitgelegd als *'een gebouw waar, ten gevolge van de hoge energie-efficiëntie van het gebouw, de totale jaarlijkse primaire energieverbruik gelijk is aan of minder dan de productie van energie uit duurzame energiebronnen op het gebouwterrein en indien nodig buiten het gebouw terrein'*. Dit betekent dat neutraliteit wordt bereikt wanneer er 0 kWh fossiele elektriciteit wordt gebruik en 0 m^3 fossiele gas wordt gebruiken in een jaar.

Door het maken van een model met behulp van de beschikbare technieken kan er worden bepaald of het mogelijk is energieneutraliteit te bereiken in bestaande kantoorpanden. De casestudie toont aan dat het mogelijk is voor een kantoorgebouw om neutraliteit te bereiken, welke ook meteen antwoord geeft op de hoofd onderzoeksvraag. Bij de casestudy is neutraliteit bereikt vanaf stap 4, waarbij duurzame energieopwekking buiten het gebouw terrein nodig is om energie neutraliteit te bereiken. De casestudie toont aan dat in sommige (of meer) gevallen het onmogelijk is (afhankelijk van de situatie ter plaatse) om neutraliteit te bereiken op het gebouwterrein niveau. Als dat het geval is, dan is energieopwekking buiten het gebouwterrein nodig om neutraliteit te bereiken. Met dit model is het ook mogelijk om meerdere gebouwen eraan te koppelen en zo met behulp van buiten het terrein gebruikte energieopwekkingstechnieken gebouwen energieneutraal te maken. Dit onderzoek toont een bottom-up benadering voor het energieneutraal maken van bestaande kantoorgebouwen, eerst door middel van een gebouw welke vervolgens gebruikt kan worden voor meerdere gebouwen. Dit betekend dat met verder onderzoek gekeken kan worden of meer gebouwen op dit model aangesloten kunnen worden en gebouwen op een grotere schaal energieneutraal gemaakt kunnen worden.

Dit model kan in de praktijk gebruikt worden voor bedrijven (en in specifiek voor Heijmans) als instrument om mee naar klanten te gaan en hen ervan te overtuigen dat energie neutraliteit haalbaar is en hierin te investeren. Heijmans kan met behulp van dit model met minimale tijd en capaciteit een overzicht geven over welke technieken er toegepast moeten worden om energie neutraliteit te bereiken. Het model gebruikt een vereenvoudiging van de toegepaste technieken, maar geeft voldoende informatie om te laten zien dat neutraliteit mogelijk is.

ABSTRACT

One of the major causes of climate change is the energy use of human activity and in specific the build environment. The built environment accounts for approximately 35% of the total Dutch energy consumption. More than half of this part is used in commercial buildings such as schools and offices (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012). Where 80% of the CO_2 emissions is caused by the operating phase of the existing buildings.

As part of this problem, this research tried to find a solution for reaching energy neutrality within the build environment and in specific, office buildings. There is no approach yet for making office buildings on a larger scale energy neutral. This research describes a bottom-up approach for reaching neutrality in office buildings. First, a definition of Zero Energy Buildings is given to show what neutrality is and when it is reached by using a literature study and expert interviews. Second, a model is proposed to show how neutrality can be reached for office buildings with current available instruments, using a System Dynamics approach. The research showed that it is possible to reach energy neutrality within office buildings. In many cases off-site generation is needed to reach energy neutrality which means that this model can also be used to connect more office buildings to the model.

For practical use, this model can be used by companies to go to their clients and convince them to invest in neutrality and show the package list of investments for reaching neutrality. The model needs minimum capacity and time to provide an optimization package per building.

CHAPTER 1 – INTRODUCTION

1.1 PROBLEM DEFINITION

'The climate changes and more and more uncertainty exists concerning the energy supply. The discussion is no longer about the need to contemplate the future of energy supplies but about the way we can meet the future energy demand in a sustainable way. Given the massive growth in new construction in economies in transition, and the inefficiencies of existing building stock worldwide, if nothing is done, greenhouse gas emissions from buildings will more than double in the next 20 years' (UNEP SBCI & Sustainable United Nations, 2009).

Energy use, and the associated carbon dioxide emissions, has been rising rapidly over the past few decades. The main consumers are the developed countries. The consequences of the continuing growth of energy use which this implies are potentially catastrophic. The developed countries have to improve their energy efficiency as a part of ensuring that the problem is brought under control. As for most developed countries, the energy system in the Netherlands is largely driven by the combustion of fossil fuels. In 2009, natural gas is supplying about 45.0% of the total primary fuels used in the Netherlands, followed by liquid fuels (38.0%) and solid fossil fuels (9.6%). The contribution of no fossil fuels, including renewable and waste streams is rather limited (van der Maas, et al., 2011).

Besides the increase of greenhouse gas emission, energy mostly from fossil sources, will greatly increase in price in the future because of the looming shortage of (affordable) fossil energy in conjunction with the 'supply'. The use of fossil-fuel-derived energy in the production of materials, during the construction process, and by the occupants or users of the building or structure throughout its lifetime is a source of significant quantities of carbon dioxide. Though not the most potent of the so-called greenhouse gases, it is the one produced in the greatest quantities (Willmott Dixon, 2010).

The built environment accounts for approximately 35% of the total Dutch energy consumption. More than half of this part is used in commercial buildings such as schools and offices (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012). Office buildings have one of the highest levels of energy consumption compared with other building types. The annual energy consumption in office buildings varies between 100 and 1000 kWh per m^2, depending on geographic location, type and use of office equipment, operational schedules, type of envelope, use of HVAC and lighting system and so on (Juan, Gao, & Wang, 2010). The energy consumption concerns both building related and not building related applications such as office equipment (Energy in the Netherlands, 2011).

The full extent of the life-time emissions of a building can best be understood by using the life-cycle (LCA) approach. The LCA approach reveals that over 80 percent of greenhouse gas emissions take place during the operational phase of a buildings when energy is used for heating, cooling, ventilation, lighting, appliances, and other applications. In developed countries, the majority of buildings which will be standing in 2050 have already been built, so policies should encourage building owners to retrofit their buildings in such a way as to optimise emission reductions (UNEP SBCI and Sustainable United Nations, 2009).

This is supported by further research of the operational phase. Further research shows that a third of the CO_2 emissions in Netherlands in the year 2013 is related to energy use in the operating phase of existing buildings. The most important part are approximately 3.5 million existing buildings from before 1975, which accounts for half of the Dutch building stock. There is a major energy saving potential in these buildings and with that a reduction of the CO_2 emissions, but also adding comfort and improve health conditions. Knowledge and resources to improve existing homes and buildings are therefore of great importance for the achievement of social and sustainability goals (Levine, et al., 2007).

As previous stated energy, mostly from fossil sources, will greatly increase in price in the future because of the looming shortage of (affordable) fossil energy in conjunction with the 'supply'. Energy neutral- buildings and renovating is desperately needed to keep housing affordable (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012). By lowering the energy consumption or the transition from fossil fuels towards green (renewable) energy sources in existing building the greenhouse gas emission will be lowered, and the problem of the looming shortage of fossil sources will be prevented.

1.1.1 Problem context related to the company

Since 2006 sustainability is of high importance on the agenda of Heijmans. Since 2006 considerable progress has been made in the greening of the business, the chain and the products and services. Heijmans wants to reduce the CO_2 emissions as an objective part of a broad sustainability vision known as ‘the contours of the future’. A vision that led Heijmans persuading an optimal balance between people, planet and profit. The activities for the long-term goal are formulated to reduce the footprint. One of those goals for 2012-2016 is to reduce the CO_2 emission in four years with 6% (Heijmans, 2014). A part of the vision known as the ‘contours of the future’ is that the products they make will generate energy instead of costing energy (Heijmans, 2014). As part of this design the department utility is currently trying to identify more solutions in gaining insight in energy-saving solutions for their products. It is an optimal combination with this research, since this research will gain insight into making existing buildings energy neutral.

The department utility designs, builds and maintains high-quality electrical and mechanical installations. Utility achieves scale and complex building projects in customer and healthcare, (semi-) government, commercial real estate, high tech clean industry (such as laboratories) and data centres. A unique feature is the integrated approach to construction and installation and jobs are increasingly linked to long-term management, maintenance and service.

1.2 PROBLEM STATEMENT

The climate changes and more and more uncertainty exists concerning the energy supply. Currently in the Netherlands, 35% of the total energy supply is caused by the build environment and a large part of that caused by existing office buildings, which produce the highest energy demand in comparison with other building types. At this moment there are many impressive technical innovations which are aimed at reducing the energy use and even are trying to make buildings energy neutral. However, it is still not yet managed in the Netherlands and elsewhere in Europe to make existing buildings on a large scale energy neutral (GEN, Idema, and de Koning, 2014). This raises the question if it is possible to make existing buildings – and in specific office building – energy neutral and if so, how and could it be used on a larger scale? This research looks into this problem by first identifying what energy neutrality includes and if it is possible to make office buildings energy neutral and if so, if it possible to apply this on a larger scale.

1.3 RESEARCH QUESTION

This research proposal aims to provide information about how to make existing office buildings energy neutral with technologies which are currently available on the market. The research question that combines this content is proposed as:

> What is the feasibility of energy neutrality in existing office buildings with current instruments?

In order to answer the main research question, the following sub-questions have been formulated:

RQ1	What is energy neutrality and when is it reached?
RQ2	What kind of energy improvement tools are available on the market and can be used to make a building energy neutral?
RQ2.1	What kind of energy improvement techniques are available for building specific optimization?
RQ2.2	What kind of sustainable energy generation techniques are available for on-site and off-site generation?
RQ3	What are the limitations regarding energy reduction based on energy efficiency and indoor climate requirements?
RQ4	How can the techniques gathered from sub question 2 and 3 be used, so that it is usable for modelling?
RQ5	How can the usable tools be combined so that a model can be made in order to simulate the energy usage of an existing building?

1.4 RESEARCH DESIGN

The purpose of this research is to make existing office buildings energy neutral. The process of this research will consist out of several phases that need to be accomplished. The tools that are used during this process are a literature review, expert interviews, a model based on System Dynamics and a case study. Figure 1 shows an overview of the steps that are taken during the research.

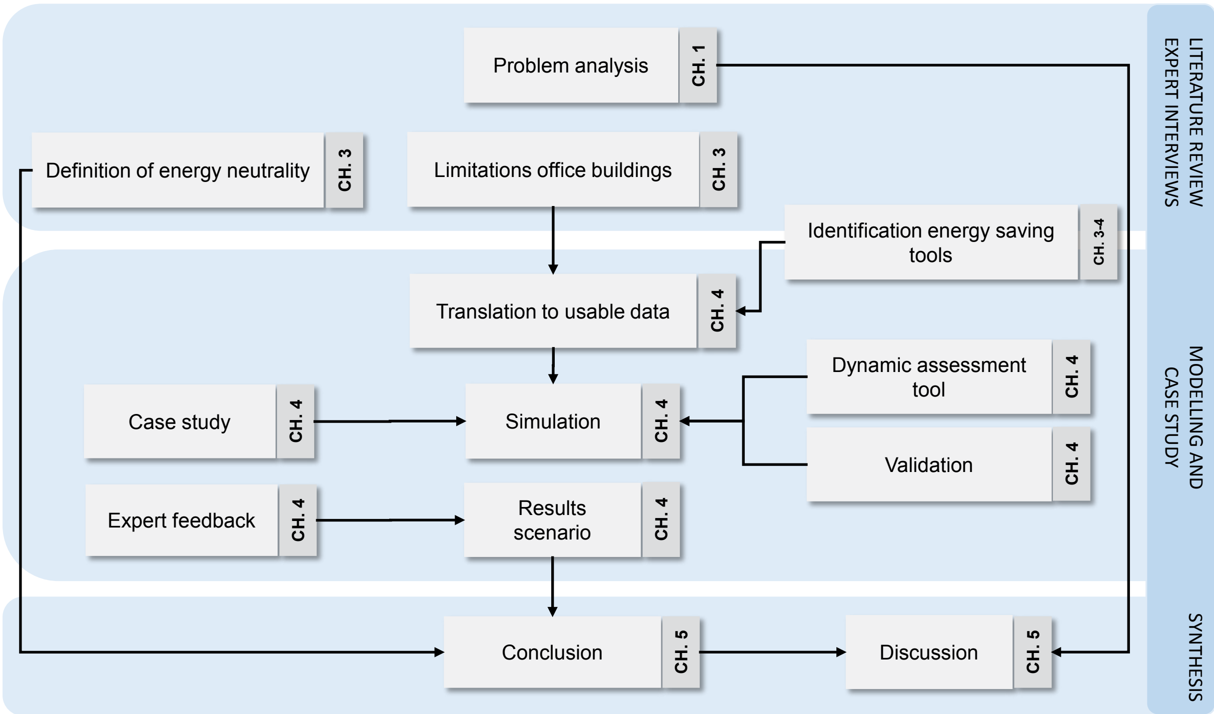

FIGURE 1 – RESEARCH DESIGN

1.4.1 Tool explanation

Literature review – a literature review has been carried out to provide knowledge and information about what energy neutrality is and what the different methodologies for reaching it are in the different literature studies. Besides the definition of energy neutrality, the limitations of the optimization in office buildings are researched in the literature. This information is needed for the model to show what the limitations are regarding building and system optimization (e.g. energy efficiency) and indoor climate (e.g. indoor comfort). The main databases that are be used are journals and magazines in the field of environmental management, energy policy, energy economics and the built environment that cover the topic energy neutrality by using keywords related to energy neutrality such as Zero Energy Building and energy efficiency. The information resulting from this research contributes to answering sub question 1 and 3.

Expert interviews – interviews with employees of Heijmans have been instrumental in supporting the scientific knowledge gained from the literature. The expert interviews were held to give a practical view on energy neutrality and how it is done in practice. Experts within the field of sustainability and energy have contributed to developing a well-founded definition on the concept of Zero Energy Building (energy neutrality). The information from practices differs from the literature on some point, which contributes to a large extend to the relevance of this research in finding a clear and consistent definition of Zero Energy Building. The data collection was done by using a semi-structured face to face interviews which was analysed by using grounded theory. The information resulting from this research contributes to answering sub question 1 and 3.

System Dynamics – the second phase of the research exists identifying and modelling the current available techniques which can make office buildings energy neutral. Each building needs a different approach for reaching energy neutrality which cannot be generalized or standardized. In that case the best option for modelling this problem is System Dynamics (SD) which is a methodology and mathematical modelling technique for framing, understanding and discussing complex systems which are not linear (Sterman, 2000). SD is in specific used for this research to understand system behaviour of the different technologies and see what the influence is of the different input data by using simulations. The information resulting from this research contributes to answering sub question 2, 4 and 5.

Case study – the goal of the case study is to verify the initial situation and the assumptions made throughout the research. But also to verify the model and test a specific case about what the measure package has to be in order to reach energy neutrality. This measure package is compared with an available report on energy reduction. For the case study the main building of Heijmans is used due to the information that was available of the building and the information which can be used for validation purposes. The information resulting from this research contributes to answering the main research question.

1.4.2 Expected results

The main result of this research will be a model which can show for each individual existing office building whether or not it can reach energy neutrality and if so with what measures to take in the form of a building specific measure package. The model should provide insight in the dynamic behaviour of the different used technologies and what their relationship is between each element. Each case (a specific building) that is inserted should provide a building specific measure package which will be unique in every case. The techniques are the same, but the effects of each technique will differ. For example, each building that is inserted into the model will give a different result in energy reduction or generation, because no building is the same and the input data will differ in each case.

In order to make the model first an overall definition needs to be formulated about what energy neutrality is and when it is reached. This means that this research provides a new or existing definition on energy neutrality in order to use and test the model with.

When making the model, insight should be gained in the different technologies that are available on the market and what their limitations are and when they should be used. And when the model is made it should provide information about the interrelationships between the technologies.

CHAPTER 2 – GLOSSARY

The aim of this research is answering the main research question stated as *'what is the feasibility of energy neutrality in existing office buildings with current instruments'.* During the research several definitions, notion and classifications are identified. This chapter summarizes the explanation of each by chapter.

Chapter 3.3 – In order to formulate a consistent definition of zero energy buildings a literature review is executed. In this chapter a methodology matrix is made to see what aspects are part of a zero energy building definition. These variables are the key words that are used throughout the whole research. Below, the main variables found in the literature are explained.

Characteristics	*Explanation*
ON-SITE GENERATION	Once efficiency measures have been incorporated, the remaining energy needs can be met by using renewable energy technologies, generated within the building site boundaries. E.g. generation of renewable energy within the building footprint or on the building site (on-site).
OFF-SITE GENERATION	Renewable energy generation outside the building site boundaries. E.g. locations everywhere, but the building site itself.
CO_2 EMISSION	The emitted CO_2 by the burning of fossil fuels.
COST ANALYSIS	A systematic approach to estimating the strengths and weaknesses of alternatives that satisfy transactions, activities or functional requirements.
GRID CONNECTION	When power is supplied outside its own boundaries. A building is grid connected when it is connected to power sources where the energy is transmitted over a long-distance.
MEASURED DATA	Data which is determined by measurements, for this research this applies on energy usage streams.
REFERENCE DATA	Reference data are the data objects relevant to the energy use or reduction, consisting of sets of values, statuses or classification schema. In this research mainly explained as climate data.
SIMULATED DATA	Simulation data is the data generated from the imitation of the operation of a real-world building where energy neutrality is tested over time.
BUILDING REQUIREMENTS	A set of rules that specify the minimum standards for a building (i.e. building structure related or non-building structure). In this research the building requirements are analysed in relation with efficiency measures.
NEW BUILDING	A building which is not yet build where in the design phase all the decision for optimization or reduction can still be made.
EXISTING BUILDING	A building which is already build, where new decisions have significant effect on the existing building.
ANNUAL DURATION	Yearly information which can be used for analysing energy stream in a specific phase of the building.
LIFE CYCLE DURATION	Life cycle duration determine the total environmental impact of a building throughout its entire life cycle, i.e. extraction of the necessary raw materials, manufacturing, transportation, use and waste

Chapter 3.3 – five definitions for reaching zero energy buildings are discussed, the different definitions are summarized including their main characteristics.

1. ZERO ENERGY BUILDING – a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on-site.

Characteristics	*Explanation*
EPC	The energy performance coefficient (EPC) is the evaluation of the energetic quality of existing and new buildings (residential and commercial) and to quantify and control energy neutrality in the future or energy-generating buildings. Focused on building related energy use.

2. METRIC BALANCE OF ZERO ENERGY BUILDING – a building which produces as much energy as it uses over the course of a year.

Characteristics	*Explanation*
SITE ZEB	In zero site energy building, for every unit of energy the building consumes over a year, it must generate a unit of renewable energy on-site.
SOURCE ZEB	The balance between the primary energy that is needed to extract and deliver energy to a site, including the energy that may be lost or wasted in the process of generation, transmission and distribution and the energy use of the building.
ENERGY COST ZEB	The balance between the amount the owner has to pay for utility, for energy services and energy uses over a year and the amount of money the utility pays the building owner for energy the building exports to the grid. Where a building has an energy utility bill of €0 over the course of a year.
EMISSION ZEB	A building produces at least as much emission-free renewable energy as it uses from emission producing energy sources

3. ZEB BY CLIMATE DATA – a building that is made energy neutral by using climate specific technologies. With the reference data a building can be simulated and shown if it reaches energy neutrality.

4. PERIOD OF ZEB – the primary energy used in the building in operation plus the energy embodied within its constituent materials and systems, including energy generating ones, over the life of the building is equal to or less than the energy produced by its renewable energy systems within the building over their lifetime.

5. ON-SITE OR OFF-SITE ZEB – the energy needs can be met using renewable energy technologies, either from on-site generation or off-site generation. Whereas on-site ZEB means, that by using on-site renewable energy the building can be made energy neutral and whereas off-site ZEB means, by using off-site renewable energy technologies the building can be made energy neutral.

Characteristics	*Explanation*
ON-SITE GENERATION	• The use of renewable energy sources available within the buildings' footprint • The use of renewable energy sources available on-site.
OFF-SITE GENERATION	• The usage of renewable sources available off-site to generate on-site • The purchase of off-site renewable energy sources

Chapter 3.4 – this section focus is on energy efficiency measures, energy efficiency can be done by applying three steps:

ENERGY EFFICIENCY MEASURES

Characteristics	*Explanation*
PREVENTION OF HEAT LEAKAGE	The prevention of heating generated by a climate system that is lost by leaks in the walls, windows and thermal bridges.
THE RECOVERY OF ENERGY	The recovery of energy generated by the installed systems for example installing balanced ventilation with heat recover or air heat pumps with waste water recovery.
LIMITATION ENERGY DISTRIBUTION	The adjustment of people by changing the overall average temperature of the building or the prevention of electronica energy distribution by shutting down the electronica when not used.

Chapter 3.5 – this section focuses on a practical view of zero energy buildings. For this, a qualitative research is performed the main research method is explained next:

QUALITATIVE RESEARCH (GROUNDED THEORY) – collecting and analysing nonnumeric data with the aim of achieving information depth. Grounded theory allows the discovery and development of a substantive theory generated from the research data to explain unique viewpoint of the expert reflecting their experiences of the problem they encountered and how they overcame these (Glaser, 1987; Glaser and Strauss, 1967).

Chapter 3.6 – this section proposes the overall definition and methodology which will be used throughout this whole research. The Zero Energy Building definition and methodology is proposed as:

ZERO ENERGY BUILDING DEFINITION – '*a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources from on-site supplies and if necessary off-site supplies*'.

METHODOLOGY – Zero Energy Building can be described as the use of 0 kWh electricity and 0 m^3 gas in a year. In short: | export |-| import|≥ 0 in time=1 (years). This means that if a building produces 0 kWh fossil electricity and 0 m^3 fossil gas in a year in a given year, the building is labelled as energy neutral.

Characteristics	*Explanation*
I BUILDING OPTIMIZATION	Reducing building energy use trough optimizing the building envelope and the prevention of energy losses. And trough low-energy building technologies.
II GENERATION ON BUILDING FOOTPRINT	The use of renewable energy sources available within the buildings' footprint (e.g. PV, solar panels and wind).
III ON-SITE GENERATION OF RENEWABLE ENERGY	The use of renewable energy source which are available on the building site, not on the building itself (e.g. PV, solar panels and wind).
IV OFF-SITE GENERATION OF RENEWABLE ENERGY	The use of renewable energy sources available off-site to generate energy on-site (e.g. biomass)
V OFF-SITE SUPPLY	Purchase of off-site renewable energy sources

Chapter 4.2 – in this section the method System Dynamics (SD) is explained.

SYSTEM DYNAMICS – methodology and mathematical modelling technique for framing, understanding and discussing complex systems (Sterman, 2000)

Steps	*Explanation*
STEP 1 – THEORETICAL BACKGROUND	In the first step of the research, the definition of the problem and the method are given. The basic principles which are the foundation of System Dynamics are reviewed in order to create a framework for the rest of the research
STEP 2 – FEEDBACK SYSTEM	The feedback system is created in order to describe relevant feedback loops. These feedback loops are the foundation of the System Dynamics model. In the loops, the parameters that influence each other are given. A causal loop diagram contains a number of variables, which are connected by arrows with a causal relationship (causal chain). Which exists of either a positive (+) or negative causal relationship (-). It is an important tool to show the feedback structure of the system (Ventana Systems, inc., 1989-2012).
STEP 3 – THE SYSTEM	In this step, the System Dynamics model is created. This is done by creating subsystems that are founded on one of the feedback loops as created in step [2]. The stock and flow diagram is a further description of the system based on the causal relationship explained in the causal loop. It reflects the logical relationship among the system elements clearly and clearly shows the cumulative effects and rate of change of each variable (Ventana Systems, inc., 1989-2012).
STEP 4 – VALIDATION	Validation of the (sub) model(s) is mostly done by using one of two options: using historic data to see if the model follows the patterns that occurred in the past or by using a case study in order to find out if the system is correct for a specific situation. In this research there is chosen for a case study which is validated by experts and a report.

STEP 5 – CONCLUSION	When the model is validated, the model can start simulating the information and the results from this will be used to generate conclusions and advice on the best possible ways of action in order to influence the system and solve the problem.

Chapter 4.3 – the model is explained, next the main technologies are described for each sub system:

SUMMARY EXPLANATION OF VENSIM MODEL

1.1 building optimization	
CAVITY WALL INSULATION	The reduction of heat leakage from the building envelope by insulating the cavity wall.
ROOF INSULATION	The reduction of heat leakage from the building envelope by insulating the roof.
FLOOR INSULATION	The reduction of heat leakage from the building envelope by insulating the floor.
HR PLUS INSULATION	The reduction of heat leakage from the building envelope by replacing the windows.
1.2 system optimization	
VENTILATION	Ventilation is necessary for a healthy building. Besides supply of fresh air, ventilation air can also be used to heat the building, cooling or moistening. For the model, the best technique regarding energy reduction is a demand controlled ventilation system, which is based on presence detection.
HEATING BOILER	In order to heat the rooms in the building, there is a heat source needed. The best efficient heating system available at this moment is a HR107 boiler with an efficiency of 107%.
COOLING	In many office buildings cooling is present to prevent the building becoming too hot in the summer. The most efficient system for cooling at this moment is dew point cooling with a COP of 17.3.
LIGHTING	Lighting is needed in an office building, the reduction of energy by lighting can be done in three ways, 1) changing lighting system for efficient lighting bulbs, 2) installing presence detection and 3) day light depended lighting system.
SUN SHADING	There are several techniques to prevent diffuse and direct sunlight from entering through the windows, by using sun shading. It is possible to apply sun shading on the outside, inside or a combination of the two. Outside automatic screens with a power of 350 W/m^2 have the most significant effect on the energy reduction.
02 generation on building footprint	
SOLAR PANELS	Solar panels are panels in which a large number of photo voltaic cells are connected in series. These cells produce electricity from light. Modern solar panels convert about 15% of the energy in light into electricity.

MICRO COGENERATION	A high-efficiency boiler (or micro-cogeneration) generates electricity as well as heat. If the boiler is on the system doesn't only heat the water for heating and hot water, but also generates electricity.
03 generation on building site	
GAS HEATING PUMP	A gas heating pump can transport heat and cooling from one environment to another. For heating, from an energetic viewpoint, the best fit is gas heating pump based on a generation trough an air-water system. The heating pump has a COP of 2.7.
AIRCO HEATING PUMP	An electric heating pump can transport heat and cooling from one environment to another. For cooling, from an energetic viewpoint, the best fit is an electric heating pump based on a generation trough an air-air system. The electric heating pump has a COP of 2.3.
BIO BOILER	A biomass boiler burns unlike gas or oil-fired boilers biomass, such as pellets or wood chips. These fuels are stored in a storage tank and transported to the burner. The combustion takes place by the supply of air. The efficiency of a biomass boiler is the same as a CV boiler, 90%.
HEAT COLD STORAGE	Heat- cold storage, heat and cold stored in the groundwater of deeper layers of the earth, ranging in depth from about 30 to 150 meters of ground water has a year by a temperature of about 10 degrees Celsius, and can therefore also be used via a heat pump system for cooling .
04 off-site generation	
BIOGAS INSTALLATION INCL. COGENERATION	Combined heat and power (CHP) cogeneration of electricity and heat from a fuel. This joint production leads to less fuel being consumed than when heat and electricity are produced separately. A modern gas-fired power plant has an efficiency of about 60%. The rest of the released energy is lost in the cooling. In a CHP this energy is captured and used for heating. This total return can go up to over 90%.
BIOMASS INSTALLATION	Biogas is generated from wet organic material such as organic waste from the agricultural sector, for example manure, residues from the food industry or residues from waste and water treatment. The biomass is collected in an airtight silo where the mass is stirred and fermented by bacteria. After the fermentation process biogas is produced.
WIND TURBINE	Wind turbines convert wind energy into electricity. The kinetic energy of wind is converted to electricity. The electricity proceeds depends upon the size of the plant, type of turbine, average wind speed at a location and the location of the wind turbine

(Technologies which are used in more than one step, are explained only one time)

CHAPTER 3 – FORMULATING A DEFINITION OF ZERO ENERGY BUILDINGS

ABSTRACT

The concept of the Zero Energy Building (energy neutrality) has gained a lot of attention over the years. However, there is little consistency regarding Zero Energy Building. There are many approaches used in different views and in different contexts. With the gaining attention, Zero Energy Building requires a clear and consistent understanding and approach. In order to formulate a clear and consistent Zero Energy Building, a good definition has to be proposed. This chapter focuses on the existing definitions and the various approaches towards Zero Energy Building. The most important issues that need attention are (1) Zero Energy Building by governmental law, (2) metric balance of Zero Energy Building, (3) zero energy building by climate data, (4) period of zero energy, (5) on-site or off-site Zero Energy Buildings and as last (6) limitations. In the second part of the research a qualitative research is performed to determine what the practical view on Zero Energy Building is determined by experts. All this information is then combined to propose an overall definition which will be used throughout the whole research. This chapter ends with a clear and consistent Zero Energy Building definition and proposed boundaries and a framework which can be used as an overall guideline.

KEYWORDS: ZERO ENERGY BUILDINGS, ENERGY EFFICIENCY, RENEWABLE ENERGY, QUALITATIVE RESEARCH, LITERATURE REVIEW

3.1 INTRODUCTION

The importance of energy reduction and energy neutrality within the build environment has increased much in attention in the last few years, which means that Zero Energy Building is no longer perceived as a concept of the future. Zero Energy Building is a realistic solution for the reduction of CO_2 emissions and the reduction of energy use in the building sector (Marszal, et al., 2011). Zero Energy Building has become a part of both EU and US policies on energy efficiency in buildings. In the recast of the EU Directive on Energy Performance of Buildings (EPBD) is established that nearly-Zero Energy Buildings is the target for 2020 for all new buildings.

The concept of Zero Energy Building has various advantages, especially in terms of comfort, operation and environment, which will be further explained throughout this chapter. One of the most important advantage is that Zero Energy Building provides as a guideline in a time where the need arises to build and renovate towards an energy neutral build environment. The need for energy neutrality arises due to climate change and second, the looming shortage of (affordable) fossil energy in conjunction with the supply (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012).

The main research question of this research is stated as *'what is the feasibility of energy neutrality in existing office buildings with current instruments'*, which is further explained in chapter 1. As part of answering the main research question, first a clear and consistent definition of the term energy neutrality is needed in order to determine the approach towards zero energy. The definition will provide for an assessment framework which can be used in order to answer a part of the main research question and for testing the model in chapter 4. This chapter will give answer to what energy neutrality is and when it is reached and what the limitations are regarding energy reduction based on energy efficiency and indoor climate requirements.

The definition Zero Energy Buildings is the concept for energy neutrality within the build environment and is used for the mitigation of the energy demand regarding the building sector (Kapsalaki and Santamouris, 2012). In this context, further explanation of energy neutrality is done in the concept of Zero Energy Building and will be shortened to ZEB.

This chapter is build up in different sections, first a definition based on a governmental view is discussed in chapter 3.2. Second, scientific journals are consulted to determine the different approaches and methodologies in chapter 3.3. In chapter 3.4 the requirements for existing buildings are discussed which have to be met within the translation of ZEB. Chapter 3.5 focuses on a qualitative research to include the practice view of ZEB. In chapter 3.6 the information from chapter 3.2 to 3.5 are combined in one definition of ZEB, including the boundaries, technical approach and framework.

3.2 GOVERNMENTAL DESCRIPTION OF ZERO ENERGY BUILDINGS

Before defining the different approaches towards a good ZEB definition, a good understanding is needed regarding the governmental laws. This is necessary, since governmental and national laws are the subsurface for a well-defined ZEB definition.

3.2.1 European ZEB approach

The first step is identifying the laws on a European level. Reducing energy consumption and eliminating wastage are among the main goals of the European Union (EU), shortly discussed in the introduction. As part of the Energy Performance of Buildings Directive (EPBD) all EU countries have to enhance their building regulations. In 2010 the European adapted the EPBD, which meant that EU Member States faced new challenges. In the directive of 2010/31/EU all EU Member States have to move towards new and retrofitted nearly ZEB by 2020, and the application of a cost-optimal methodology for setting minimum requirements for both the envelope and the technical systems (Concerted Action EPBD and European Union, 2014) .

A translation of these directives were given by the European parliament and Council of the European Union, 2010 as […] *a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on-site* […].

3.2.2 National ZEB approach

The second step is translating the European laws into national laws, each EU member state has to implement the European Directive into their national legislation. In the Netherlands ZEB is defined as where the energy use of fossil fuels in buildings is compensated by renewable energy. This implies that no fossil fuels may be used. To give a better understanding on when a building is energy neutral, the government has implemented a methodology to determine if a building is energy zero. The methodology for ZEB in the Netherlands is defined as the energy performance coefficient (EPC), if the EPC of a building is zero, the building is energy neutral and is thus a ZEB. The EPC is an instrument used by the government which is predefined in the Dutch building regulations (Bouwbesluit) to evaluate the energetic quality of existing and new buildings (residential and commercial) and to quantify and control energy neutrality in the future or energy-generating building. The EPC is regulated by NEN 7120: Energy performance of buildings (EPB) and expressed as a limit on the energy performance coefficient and indicates the degree of energy efficiency of a building (Bouwbesluit online, 2012). The methodology focusses on the building-related part but not on the user part of energy usage within a building.

3.3 LITERATURE REVIEW ON ZERO ENERGY BUILDINGS

This chapter describes the main approaches of ZEB which are found in the literature. For the literature review several journals are consulted. The main journals used for this review are: Energy and Buildings, Energy Renewable energy and Build Environment.

ZEB is a relatively new complex concept with number of already existing approaches that highlight the different aspects of ZEB. The goal of reaching zero is not easy due to the calculation of the energy balance. All the different aspects such as on-site and off-site renewable energy generation systems, interaction with the grid and reference data such as location data, annual data and simulation makes the goal of one overall definition and approach not easy to reach. Some voluntary environmental assessment methods like LEED, BREEAM and GPR gebouwen do exist, yet they have much wider scope than the current frameworks for ZEB. Therefore Marszal, 2011 states that […] *if ZEB is seen as a future target for the buildings, it is a key issue to develop a physically convincing, robust and communicable calculation methodology that reflects the concept and facilitate the work of both architects and engineers in designing Zero Energy Buildings* [...].

The first step in defining the main approaches for ZEB in the literature, was analysing scientific articles which discussed the topic of ZEB with the help of keywords. The main keywords which were used were *'zero energy building'* and '*energy neutral'*. These keywords in combination with the specific journals (e.g. Energy and Buildings, Energy Renewable energy and Build Environment), provided for enough articles which could be used for further research. Each article provided several important factors, approaches and goals. All the important elements of each article are summarized in table 1.

From these articles, four main definitions and methodologies were distinguished and will be discussed in the next sub-chapters. The four methodologies that are discussed in the next sub-chapters are (1) metric balance of ZEB, (2) ZEB by climate data, (3) period of ZEB and (4) on-site – off-site ZEB.

TABLE 1 – METHODOLOGY MATRIX DEFINITION OF ZERO ENERGY BUILDING

#1 Metric balance of ZEB #2 ZEB by climate data

#3 Period of ZEB #4 On-site, Off-site ZEB

Authors	#	Renewable energy: On-site	Renewable energy: Off-site	CO_2 emission	Cost analysis	Grid in/out	Insight energy use	Location / climate data	Building requirements	Simulation	Tool focused	Time duration: Annual	Time duration: LC
Attia et al., 2013	1	√				√			√		√		
Esbensen et al., 1977	2	√						√	√				√
Ferrante et al., 2011	2,4		√	√		√	√	√	√	√			
Gilijamse et al., 1995	4	√							√				
Hernandez et al., 2010	2,3	√				√			√		√		√
Hamdy et al., 2013	2,3	√			√			√	√	√	√		√
Iqbal, 2004	1,2		√			√		√	√	√		√	
Kapsalaki et al., 2011	2,3	√			√		√	√	√	√	√		√
Marszal et al., 2010	3	√		√	√					√			
Marszal et al., 2012	1,4	√	√		√	√						√	
Marszal et al., 2012	3,4	√	√		√		√			√	√		
Sartori et al., 2010	1,4	√	√	√		√	√					√	
Sartori et al., 2012	1,2	√		√	√	√		√	√		√	√	
Salom et al., 2011	1			√		√					√	√	
Thiel et al., 2013	3	√		√					√	√			√
Torcellini et al., 2013	1,4	√	√	√	√	√						√	

√ = Includes the theme

3.3.1 Metric balance of ZEB

The four definitions of the metric balance of ZEB are identified and defined by Torcellini (2006) as site ZEB, source ZEB, energy cost ZEB and emission ZEB, displayed in table 2. The metric balance of ZEB uses as basis measured data such as energy streams from and to the building site. Metric site ZEB is the defined as the balance between the use of the site and the generated energy. For every unit of energy the building consumes over a year, a unit renewable energy has to be reprocessed. The metric balance of ZEB is further divided into four categories stated as site ZEB, source ZEB, energy cost ZEB and emission ZEB.

Source ZEB refers to the primary energy necessary in order to generate energy and deliver it to the ground, including the energy which has been lost or is wasted during the process of generation, transmission and distribution. For example, if natural gas is used at a site, it means that for every 20 joules consumed, 1 joule is needed to extract and distribute the gas to the site. Metric source ZEB account for these factors, though the exact metric can vary depending on the site situation and utility factors. The metric energy cost ZEB is defined as the balance between the amount the owner has to pay for utility, for energy services and energy uses over a year and the amount of money the utility pays the building owner for energy the building exports to the grid. Which means that the building has an energy bill of zero over a year. The grid is used both as an ideal source and an ideal storage medium and energy losses are not taken into account during the energy supply between transportation from and to the grid and building (Attia et al., 2013). And as last the emission ZEB, where a building produces at least as much emission-free renewable energy as it uses from emission producing energy sources (Torcellini et al., 2006).

TABLE 2 – ZEB DEFINITION BY METRIC OF BALANCE

Authors	Site ZEB	Source ZEB	Energy cost ZEB	Emission ZEB
Attia et al., 2013	√			
Esbensen et al., 1977	√			
Ferrante et al., 2011				√
Gilijamse et al., 1995	√			
Hernandez et al., 2010		√		
Hamdy et al., 2013			√	
Iqbal, 2004		√		
Kapsalaki et al., 2012		√		
Marszal et al., 2011			√	
Marszal et al., 2012			√	
Sartori et al., 2012	√			
Salom et al., 2011				√
Thiel et al., 2013	√			

The most common used ZEB definition for a metric of balance is the balance between energy use and renewable energy generation used by Marszal (2014), Sartori (2010) and Torcellini (2006). The main steps that are made in this process are reducing the energy demand trough energy efficiency measures and the generation of electricity, either by site or source. In conclusion, the balance of goals differs per approach, each has its own difficulties.

3.3.2 ZEB by climate data

Another approach used in the literature is an approach where ZEB is defined by reference data (e.g. annual reference data). Where the reference year consists of a set of climate data of the location for environmental engineering (see matrix in table 3, chapter 3.3.5). This approach is useful for computerized calculations of indoor climate and energy demands. This approach is used in various articles by Esbensen (1977), Ferrante and Cascella (2011), Hamdy (2013), Iqbal (2004), Kapsalaki (2012) and Sartori (2012). The climate data is used as reference to determine what the possibilities are regarding renewable energy systems that are depended on weather conditions, such as solar panels and wind turbines. In that case the climate data of each country can be determined and the options regarding renewable energy sources – which are depended on weather conditions – can be included or excluded.

A second approach for using climate data and location data is used by Kapsalaki and Santamouris (2012) and Sartori (2012), they use in their articles the data as basis for the optimization of the building itself. Every country and its conditions (extreme heat or cold) have a different effect regarding the building requirements. Esbensen (1977) solely uses the climate data and the standard energy use of a building to determine the ZEB. The balance of the ZEB is then determined by the possible energy usage and the potential of the renewable energy based on climate data. Hamdy (2013) uses the second approach in combination with a different methodology. In his article they use the climate data in combination with the life cycle approach which is further discussed in chapter 3.3.3. In that case the climate data is used to determine the possibilities for renewable resources in the design phase before the building is build.

In the literature comes forward that this method is mainly used for new buildings instead of existing buildings, while it can also be effective for existing buildings. Only Iqbal (2004) uses the climate data in combination with the optimization of an existing building. The optimal weather conditions (e.g. strong wind, high number of solar hours etc.) of the climate are used as a main – and in this specific article the only – source of renewable energy. This articles shows that if a climate condition for example wind provides enough consistent renewable energy, it is possible to make a building energy neutral with only the help of climate conditioned renewable energy sources. A last approach with climate data can be found in the articles of Ferrante and Cascella (2011), Hamdy (2013) and Kapsalaki and Santamouris (2012), they use a reference buildings on the same location to simulate the options and potential of a new building on that same location.

In conclusion, the climate data is used to gain insight in the location data to determine which renewable energy generation systems from environmental weather conditions is optimal to use for a specific location. This approach shows that by using the surroundings, a different perspective is given towards optimization of a buildings' energy supply source. Climate data shows the potential of different types of energy sources.

3.3.3 Period of ZEB

The next approach is the period of ZEB. ZEB can be defined by using two different approaches one, by using annual data as explained in chapter 3.3.2 and two, by using a life cycle (LC) approach. Hernandez and Kenny (2010) conclude in their article that LC is a missing factor in the definition of ZEB. The focus is mainly on energy in use and ignore factors such as embodied energy. In various other scientific articles a distinction is made in the ZEB definition by life cycle (LC) approach. LC ZEB is formulated by Esbensen and van Korsgaard (1977) as [...] *the primary energy used in the building in operation plus the energy embodied within its constituent materials and systems, including energy generating ones, over the life of the building is equal to or less than the energy produced by its renewable energy systems within the building over their lifetime* [...]. This approach is also used and supported by Hernandez and Kenny (2010), Hamdy (2013), Kapsalaki and Santamouris (2012), Marszal (2011) and Thiel (2013).

Marszal (2011) forwards the argument on how far to go regarding energy efficiency measures, and when to start applying renewable energy technologies. In the case of the LC approach the energy efficiency and economic efficiency can be reconsidered right form the early design stage to determine on how far to go with energy efficiency. For example, a type of wall can be chosen based on its efficiency, but the wall may not be chosen when the wall cannot be reused. In various articles another elements is added, namely LC costs. The LC method is in many cases used in combination with cost-optimization to determine the optimal combination regarding energy efficiency and when to start applying renewable energy technologies (see table 3 in chapter 3.3.5). The life cycle approach has as main benefit that it doesn't focuses only on the lowest energy level of fossil fuels, but also on the optimal combination of tools regarding energy technologies as explained previously.

As can be seen in chapter 3.3.4 there are different approach regarding energy supply options via on-site or off-site tools. Marszal (2012) tries to identify whether on-site or off-site tools should be used in combination with LC cost approach regarding ZEB. In their research comes forward that this combination leads to findings of cost-optimal level of energy efficiency for the ZEB, and which renewable supply options should be included in ZEB. The limitation in this research is the limit amount of renewable solutions.

Summarizing, including the life cycle approach in the ZEB definition ensures that the limitation of only focusing on energy usage in the exploiting phase of the building will be gone. The LC approach in combination with cost approach ensures that there is also an optimal combination regarding energy efficiency and renewable energy technologies. However, it must be said that the LC approach cannot be used in its current form with existing buildings, since the building are already build and the design is already set. It can however be used when the building undergoes a renovation, then the LC approach can be used when the renovation design and implementations take place.

3.3.4 On-site or off-site ZEB

The last approach can be formulated as the ZEB definition by on-site or off-site energy supply options. Whereas on-site energy supply options can be explained in two ways, first the use of renewable energy sources that are available within the building's footprint (e.g. PV, wind on building solar etcetera) and second, the use of renewable energy sources available on-site (e.g. low-impact hydro, wind on-site etcetera) (Torcellini et al. 2006). The off-site energy supply options can also be explained in two ways, first the usage of renewable sources available off-site to generate energy on-site (e.g. biomass, ethanol, waste streams etcetera) and second, the purchase off-site renewable energy sources (e.g. utility-based wind, PV, emission credits etcetera) (Torcellini et al. 2006). Whereas the ZEB is determine through either a balance of energy through on-site options, off-site options or a combination of the two.

In various articles the distinction between on-site ZEB and off-site ZEB is made. Ferrante and Cascella (2011) use the general ZEB definition in combination with on-site CO_2 emission. The ZEB is then defined as the zero energy balance as well as resetting the on-site CO_2 emission to zero by using on-site energy supply options with zero CO_2 emission such as solar and wind energy. The opposite is using off-site supply options. Both Ferrante and Cascella (2011) and Iqbal (2004) use this approach in their articles. Ferrante and Cascella (2011) argue that the most common approach for ZEB is to use the electricity grid both as a source and a sink of electricity, thus avoiding the on-site electric storage systems which is supported by Iqbal (2004).

As last a combination of on-site and off-site energy supply options is made and is discussed by Marszal (2014), Marszal (2012), Sartori (2010) and Torcellini (2006). All argue that the energy supply options have to follow the location of the energy supply option with respect to the building. They point out the importance of a hierarchy of supply options based on geographical parameters. All point out the different levels starting with the highest level of (I) generation on building footprint (II) on-site generation from on-site renewables (III) on-site generation from off-site renewables (IV) off-site generation and as last (V) off-site supply, which can be seen in figure 2.

FIGURE 2 – OVERVIEW RENEWABLE ENERGY SUPPLY OPTIONS, SOURCE: MARSZAL ET AL., 2014

As can be seen in table 1, discussed at the beginning of this chapter, the preference of on-site or off-site is on-site ZEB. However, it must be pointed out that on-site options are limited regarding area, roof or building envelope etc. not every location has an optimal on-site situation which can be used for making a building energy neutral solely from on-site tools. For an optimal ZEB, a combination of on-site and off-site options is needed. Also Ferrante and Cascella (2011) state that the importance of ZEB cannot be reached by technology alone, but through an integrated design which combines passive tools (e.g. high thermal mass brick wall, solar shading, e.g. building optimization) with solar and wind energy micro-generation.

3.3.5 Summarization of the ZEB definitions

Chapter 3.3.1 to 3.3.4 described each a different approach regarding a ZEB definition and a methodology each approach has different characteristics regarding its methodology. Table 3 provides an overview of each approach discussed in the previous chapters. The table describes each ZEB approach with its most important characteristics which needs to be included in the methodology. As can be seen in chapter 3.3.1 to 3.3.4 the literature does not use specific one approach, but in many cases a combination of the different metric balance ZEB approaches.

TABLE 3 – IMPORTANT ELEMENTS FOR EACH ZEB DEFINITION AND METHODOLOGY

	National code of ZEB	Metric balance of ZEB				ZEB by climate data	Period of ZEB	Generation	
Important elements in definition		Site	Source	Energy cost	Emission			On-site	Off-site
Energy efficiency	√								
EPC of zero	√	√	√	√	√	√	√	√	√
Site renewable energy		√		√		√	√	√	
Off-site renewable energy			√	√					√
CO2 emission					√				
Cost analysis				√		√			
Grid in/out			√	√	√	√			√
Insight in energy usage		√		√					√
Location data		√			√	√		√	
Building requirements		√			√	√	√	√	

3.4 LIMITATIONS OFFICE BUILDINGS

New buildings and existing buildings ready for renovation have to meet a number of requirements. These requirements influence the chances of reaching energy neutrality, but also provides boundaries which state the limitations for ZEB. This chapter describes the measures that have the most significant influence on the ZEB and the limitations of the measures. The two measurements that are discussed are (1) energy efficiency and (2) the indoor climate.

3.4.1 Energy efficiency measures

Torcellini (2006) stated that ZEB can be described as […] *a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies* […]. In the literature different approaches were found for applying energy efficiency measures and regarding what measures are needed to give an optimal energy efficiency. Which implies that energy efficient measures need to be included for ZEB as well. As explained in the introduction the focus of this research is on existing buildings, ready for renovation. This means that the focus of the research on energy efficiency measures is done in the context of existing buildings.

The most important factors found in various sources on energy efficiency measures are specifications of the building type, local climate and the study period. These measures form the basis of energy efficiency measures (Kneifel, 2010; Cole and Kernan, 1996). The second step in identifying the optimal energy efficiency measures is identifying the different sub-categories of energy efficiency measures. Overall, three categories were identified in relation to renovation. The first category is the identification of heat leakage from the building envelope. Heat leakage occurs when buildings do not have a good insulation value and have thermal bridges which causes heat loss. They both are responsible for the loss of heating which is produced by the heating system. By preventing heat leakage, buildings need less energy for keeping the building heated.

Many articles addressed the issue but use it through individual components instead of the entire building system such as different glass façade designs, double pane, and low reflective windows etcetera (e.g. Cole and Kernan (1996)). Högberg (2009) uses a different approach and uses an integrated design that has every element in it which causes heat leakage. They explain that the reduction of heat leakage can be done by sealing leaks in the walls, windows, thermal bridges and extra insulation in the building and provide together an energy efficiency measure instead as an individual component. In the Netherlands the heat leakage is determined by the R_c value, which means thermal heat resistance and indicates the ability of heat-insulating.

From a practical view, Isover (2014) looked at the limitations in terms of ZEB for the building envelope based on the above described energy efficiency measures. They addressed the boundaries regarding shell insulation, but then in combination with an EPC of zero. They researched and calculated the effect of different R_c value in combination with the effect on the EPC. They found out that there is a maximum in energy efficiency regarding insulation measure (expressed in the R_c coefficient). Further increasing the R_c coefficient has little effect on the overall energy performance coefficient. With a R_c value of 4.0 for the façade and 6.0 for the roof, an EPC of 0.6 is feasible and is the most energy efficient. These values will be used as limitation measures regarding energy efficiency. To determine the other values for energy efficient measures the values of the Dutch building code for new buildings is used.

The second category Högberg (2009) addresses is the recovery of energy loss by the installed systems. The recovery can be done by installing balanced ventilation with heat recovery and/or air heat pump and waste water recovery. Hoevenagel (2012) uses this approach as well in his article about energy saving monitor in the Netherlands, but breaks the category heat leakage further down. He identifies three sub categories, namely heating systems, refrigeration systems and summer refrigeration systems. Each further described in exact tools used in a building such as a HR-boiler, heating pumps etc. The third category is the limitation of energy distribution. This can only be achieved by changing the beliefs of the people who are working in the building. For example, adjust the temperature in the whole building from a standard of 21 degrees to 19 degrees. But, for lowering the temperature there are restrictions which need to be reconsidered and are discussed in the next chapter.

The dGmR (2013) provides a practical view on the determined sub-categories and provide a measure package for energy optimization regarding energy efficiency in the Netherlands. They provide the standard measures that have to be taken for renovating existing utility buildings, as foundation values of the Dutch building code. The list of measures can be found in table 4. As can be seen, the first four codes point out the prevention of heat leakage, as discussed previous.

TABLE 4 – MEASURE PACKAGE UTILITY BUILDINGS

Code	*Measure*	*Value savings measure*	*Value ZEB measure*
1	Insulation façade	R_c= 3,5	R_c= 4,0
2	Insulation roof	R_c= 3,5	R_c= 6,0
3	Insulation windows	U_{window}= 1,8	U_{window}= 1.65
4	Energy efficient lighting	HF	
5	Sweeping arrangement		
6	Daylight control		
7	Wipe / daylight control		
8	Presence detection		
9	Actual fan speed control capabilities		
10	Heat recovery	70%	
11	Higher heating efficiency		
12	High-efficiency boiler		
13	High-efficiency boiler and cold storage WP		
14	HR boiler		
15	CHP		
16	DHW solar cylinder		

SOURCE: DGMR, 2013

3.4.2 Indoor climate measures

The ZEB definitions found in the different articles did not develop or addressed the indoor climate measures at all. Only a few articles addressed the indoor climate measures such as Attia (2013), Iqbal (2004), Salom (2011) and Attia (2013) use in their approach the indoor climate requirements in combination with building performance optimization. Indoor climate measures are important because people spend more than 80% of their lives indoors. Therefore, most of the time the indoor climate is the dominant factor for thermal comfort and overall well-being which influences the productivity (Höppe, 1988). To find a better understanding regarding indoor requirements, a literature review is performed to provide a better understanding of the climate requirements which can be used as part of the definition and / or methodology of ZEB. Indoor climate requirements have to be added in combination with the ZEB, since the aim is decreasing the use of energy, but still providing a good indoor climate for the occupants.

Various sources were consulted to identify the most important indoor requirements that need to be reconsidered. The translation of indoor climate can be explained as the whole of environmental parameters that affect the thermal sensation of the human being. If a person is thermally comfortable, it means that the indoor climate is optimal and there is no need for a higher or lower temperature (Boerstra et al., 2008).

To determine the most important factors regarding indoor climate is through human biometeorology, which determines that air temperature, humidity, air velocity and mean radiation temperature are regarded as the thermally relevant measures (Höppe, 1988). An optimal indoor climate can then be achieved with enough energy delivery (e.g. trough fossil fuels or renewable fuels). In the summertime a cooling system is needed to prevent high indoor temperatures. Another approach is through ventilation systems, they can prevent overheating with a zero energy demand, but there is a maximum airspeed for ventilation which must be reconsidered. The same goes for wintertime, the indoor climate can be achieved through a good heating system, but with also enough energy delivery. In Europe there is no legislation regarding indoor climate. In the Netherlands there are however some provisions concerning heat-, and cold load in the OHS regulation (Dutch: Arboregelingen). The guidelines regarding indoor climate are summarized in table 5.

TABLE 5 – GUIDELINES FOR INDOOR TEMPERATURE AND AIR IN OFFICES (BASED ON NEN-EN 7730)

Class	Operative temperature (°C)		Vertical temp. gradient (°C)	Maximum airspeed (m/s)	
	Summer	Winter		Summer	Winter
A	23-26 + II*	20-24 + II*	< 2	0.12	0.10
B	23-26	20-24	< 3	0.19	0.16
C	22-27	19-25	< 4	0.24	0.21

*. II: individual influence of temperature **SOURCE: BOERSTRA, ET AL., 2008**

In many cases the optimization of the energy performance goes hand in hand with a good indoor climate. Buildings who have been transformed where there is little heat loss and windows with a low transmission loss will ensure that the risk of drafts are also minimized (Karlsson and Moshfegh, 2006). But, more indoor comfort requires more energy instead of less energy.

3.5 QUALITATIVE RESEARCH ON ZERO ENERGY BUILDINGS

In the previous chapters the theoretical side of ZEB was discussed. The aim of this qualitative study is to better understand the practical experience of ZEB in the field. The qualitative study uses a grounded theory methodology to generate a substantive theory of the experience of advisors within a construction company with experience related to energy and sustainability.

3.5.1 Study design

In order to develop concepts which help to understand ZEB in practice (natural settings), the emphasis is on the meaning, experience and views of the participants (Pope and Mays, 1995). This technique is called a qualitative research and is especially useful for collecting and analysing nonnumeric data with the aim of achieving information depth. For the evaluation of the data, grounded theory is used which involves systematic theory that is grounded in, or based on, the observations (Schutt, 2011). Grounded theory allows the discovery and development of a substantive theory generated from the research data to explain unique viewpoint of the experts reflecting their experiences of the problem they encountered and how they overcame these (Glaser, 1978; Glaser and Strauss, 1967).

3.5.2 Research sample, setting and recruitment

Six experts of Heijmans were recruited for the study and were contacted via email. The expert were selected by their background based on the keywords 'energy', 'sustainability' and 'advisor' in the departments of housing, real estate and utility. They were provided with an information sheet outlining the study and informed consent was obtained prior to each interview. The first expert, D. Timmermans is an expert on the area of technology development and is a business developer who is working on new technology related to the build environment. The second expert is T. Smits who is the coordinator of sustainability for Heijmans. The third expert is P. Koch who is an advisor for Heijmans regarding energy and sustainability. The fourth expert is K. Dorst who is a business advisor focusing on energy saving, neutrality and maintenance for the Heijmans buildings and other projects. The fifth expert is R. Koolen which is the director of strategy and innovation for Heijmans. The last expert is H. van Hauwe and is also an advisor of sustainability for Heijmans.

3.5.3 Data collection and analysis

Data was collected through semi-structured face to face interviews in March 2015 which was recorded and later written down on paper. The translation of the recordings to paper was done through a business view approach. The questionnaire can be found in appendix 1 and the answers to the questionnaire can be found in appendix 2 to 6. The transcribed data was analysed and organized into codes (open coding) and categories (axial coding), which is essential to the development of a grounded theory (Charmaz, 2006).

The first phase of the analysis is open coding. Which is the process of 'running the data open' with data gathered from interviews (Glaser, 1978, p. 56). The answers that were given by the experts were examined line by line, sentence by sentence to identify common codes, processes or abstract concepts using the participants exact words referred to as 'in vivo codes' (Glaser and Strauss, 1967). These codes were noted on each transcribed interview representing meanings of phenomena and were then compared and contrasted for similarities and differences with other participant's interviews. This process produced a total of 29 open codes and 5 axial codes. The second phase existed of the analysis trough axial coding or selective coding which allows to filter the code data which were deemed more relevant to the emerging core variable. The identification of the core category was central, accounted for the variation of behaviours from the participants and it occurred frequently in the data.

3.5.4 Findings

As discussed previous, six experts were consulted and interviewed in March. The findings of the interviews can be found in appendix 2 to 6. In this sub chapter the open codes which represent the meaning of the phenomena and axial codes which represents the core category found in the data are described.

Next the axial codes with the open codes are described. The axial codes are formed based on the experts mentioned components and the similarities that were found between them (see table 6). As can be seen through table 6 to table 11, several open codes are only mentioned once and are also included as open codes. The reasons for this is that the investigation was limited to six experts and the experts indicated these open codes as important. Also, the open codes that were mentioned only once were also named as important in the literature (see chapter 3.3 and 3.4). The open codes that are mentioned are listed in order of frequency, and not in order of priority.

TABLE 6 – AXIAL CODES

AXIAL CODE	DESCRIPTION
1) Definition of ZEB	The different views on the definition of ZEB
2) Reasons for moving towards ZEB	Reasons for implementing ZEB in the building sector
3) Crucial factors	What needs to be done to reach ZEB
4) Methodologies	Methodologies for determining if ZEB is reached
5) Influence of the consumer	How the consumer can be influenced in using less energy

The 'definition of ZEB' in the examination is divided into six open codes. In table 7, these factors are elaborated and specified and also, how many experts have identified this factor as valuable. The *EPC = 0* is the open code that is used by all the experts. The *EPC* is the foundation of each translation, which corresponds with the in chapter 3.2.1 and 3.2.2 described European approach of reaching energy neutrality.

The translation of zero energy is by four expert called as *a building that doesn't extract fossil energy from its surrounding areas* and as a result of that, the overall *CO_2 emission* (second open code) and *energy costs* (third open code) will be lowered. This means that both *CO_2 emission* and energy costs are used as results of the translation instead of including the open codes into the translation. This approach corresponds with the in chapter 3.3 described approach, a metric balance of ZEB and in specific metric source ZEB. Where the balance is between no extractions of fossil energy which is compensated by renewable energy. The other elements *CO_2 emission* and *energy costs* are also mentioned in the literature review as an approach for reaching ZEB. In the literature review these elements were also mentioned as a part of metric balance, but at energy cost ZEB and a metric emission ZEB.

D. Timmermans (2015) translated this for a larger scale as *an area that doesn't extract fossil energy from its surrounding areas*. The expert explained this as an area where more than one building is stated and the area can be exploited for renewable energy generation. In many cases it is not possible to generate enough sustainable energy on the building site to make one building energy neutral.

K. Dorst (2015) used a different translation for ZEB and is stated as a *building related neutrality*. His argument is that buildings are used for different functions and not all functions can reach energy neutrality. For example if a building has an industrial functions which needs a lot of energy the building can still be energy neutral, but the function not. So his translation is, focus only on *building neutrality* instead of building- and usage- neutrality. However for a building with an office function, it is possible to reach energy neutrality. T. Smits (2015) brings forward that one overall translation of ZEB is not necessary. Because the aim of ZEB is wildly known and it is to build more sustainable housing to prevent global warming and extraction of limited raw materials. There is however a *communal reference framework* which is result orientated. There is already a clear result stated by the Dutch government stated as *EPC=0*. The methods on how to reach *EPC=0* however should not be determined by law, said by the majority of the experts. When this argument is compared with the literature review performed in the previous sub chapter, only the metric balance approach corresponds the best. The metric balance of ZEB specifically uses a balance without specifying how to reach it, whereas ZEB by climate data, period of ZEB and on-site or off-site ZEB do.

TABLE 7 – OPEN CODES, TRANSLATION OF ZERO ENERGY BUILDINGS

Open codes 'definition of ZEB'	Mentioned by experts	Corresponds with literature	Corresponding method
1) EPC = 0	6	Yes	Legislation ZEB
2) CO_2 emission	4	Yes	Metric balance ZEB
3) No fossil energy is extracted from the surrounding area	4	Yes	Metric balance ZEB
4) Energy costs	2	Yes	Metric balance ZEB
5) Communal reference framework	2	No	-
6) Building related neutrality	1	Yes	On-site or off-site ZEB

The second axial is 'reasons for moving towards ZEB' (see table 8). Six open codes linked to the axial code could be found in the data. The experts point out that for companies the vision of the company is an important factor for moving towards ZEB, this aspect isn't found in the literature review of chapter 3.3. In 2020 the build environment has to be energy neutral, stated in the Dutch *legislation* which is explained in chapter 3.2. However the reason for not applying ZEB as a company at this moment, is that the *requests of the clients* are not yet towards ZEB but towards energy savings in context of renovation projects. One of the reason is that the *costs and benefits* are not yet on the same line. If it is profitable to reach ZEB then the *request of the clients* will be towards ZEB instead of energy savings. And as long as the cost of fossil gas and electricity is lower than renewable energy there will be an unbalance between *costs and benefits*. Here is where the practice and literature differ, the theory found in the literature are clear and show a significant effect, however if the client does not want ZEB then all the approaches found in the literature are not applied.

But, reaching ZEB without a *cost and benefit* balance is also applied in practice. Four out of six expert support that both *PR* and *corporate social responsibility* refute that first a *costs and benefit* balance is needed before ZEB will be implemented. In many cases companies (at this moment mainly governmental companies) have an office building and want to express themselves as a sustainable company and which incorporates *social responsibility*. Those factors leads to a different view than only a *costs and benefit* balance view. However it must be said that to incorporate ZEB without a cost and benefit balance, the budget of project must be substantial enough to reach that goal, which in many cases is not. When this is not the case the clients will chose for the second best, energy saving and lowering the energy costs.

TABLE 8 – OPEN CODES, REASONS FOR MOVING TOWARDS ZEB

Open codes 'reasons for moving towards ZEB'	Mentioned by experts	Corresponds with literature	Corresponding method
1) Vision	4	No	-
2) Cost/benefit	4	Yes	Metric balance ZEB
3) PR	4	No	-
4) Request of client	3	No	-
5) Legislation	2	Yes	Legislation
6) Corporate social responsibility	1	No	-
7) Lowering energy costs	1	Yes	Metric balance ZEB

The third axial ‘crucial factors’ found in the data is about what the crucial factors are for reaching ZEB. From the data seven open codes were found and are summarized in table 9. The most named crucial factor is the *optimization of the building envelope* and was mentioned by all the experts. Four experts used optimization in combination with *optimization systems*. Both building envelope and system optimization corresponds with the in the literature review stated on-site ZEB approach.

Besides building envelope and system optimization, depending on the building an energy saving of 0% to 40% can be reached. The combination of building envelope and installation for energy reduction is also depended on the indoor climate, which was also addresses in chapter 3.4.2. The more comfort that is needed, the more energy it will cost. So if energy must be saved, the indoor requirements have to be lowered. But, the main idea of an office building is the productivity of the employees, which means that this option will not be executed in the majority of the buildings.

Two other open codes that were mentioned by five out of six experts are *sustainable energy generation* and *area solutions* which are crucial for reaching ZEB. As mentioned above with the help of building optimization and installation a maximum of 40% energy reduction can be reached, this means that there are other sources needed to generate sustainable energy. However, as mentioned by H. van Hauwe (2015) energy storage on-site at this moment is difficult and expensive, the aim should be towards energy generation until all energy flows are zero and not storage of energy. The approach of H. van Hauwe (2015) corresponds with the on-site or off-site ZEB, which also addresses that in many cases on-site generation or storage is not possible, which means off-site generation is needed.

Area solutions which corresponds with the off-site generation ZEB are discussed by the experts but have several drawbacks. First, the use of area solutions such as solar fields and windmill fields have to be bought for a long period, which binds the owner for a long time. Especially in cases where companies rent their office spaces for a relative short period this solutions will not be chosen. Another important element caused by the Dutch government is the dogmatically legislation. This prevents that measures from off-site generation can be included in the calculation of ZEB. Both T. Smits (2015) and P. Koch (2015) bring forward the importance of a more pragmatic approach regarding legislation. Due to the *insight in the energy use* of a buildings a good formulation for a plan of approach can be made, and is for two expert the first thing that needs to be done in order to make a buildings energy neutral. But due to the *(im) possibilities of the site*, the building can be made energy neutral within its building footprint or outside its footprint. In many cases the terrain does not allow energy neutrality within its building footprint. When this is the case, the experts point out the importance of using *the grid* in order to transfer the electricity from and to the building. This approach is also used in the on-site or off-site ZEB, where the on-site situation doesn’t always allows reaching energy neutrality.

TABLE 9 – OPEN CODES, CRUCIAL FACTORS

Open codes 'crucial factors'	Mentioned by experts	Corresponds with literature	Corresponding method
1) Optimization building envelope	6	Yes	On-site or off-site ZEB
2) Sustainable energy generation	5	Yes	On-site or off-site ZEB
3) Area solutions	5	Yes	On-site or off-site ZEB
4) Optimization systems	4	Yes	On-site or off-site ZEB
5) (Im)possibilities site	3	Yes	On-site or off-site ZEB
6) Insight energy use	2	Yes	Metric balance ZEB
7) Smart grid	2	Yes	On-site or off-site ZEB

The fourth axial 'methodologies' found in the data is about the methodologies that are used for calculating ZEB. From the data six open codes were found and are summarized in table 10. For office buildings, five out of six experts' mentioned the main methodology for testing energy neutrality through *BREEAM*. However, this tool is mainly used for new buildings which cannot be used for existing buildings. For this situation another tool is available and also mentioned by one expert as *BREEAM* in use and can be used in situations where the building is already been build. Though, all experts mention that *BREEAM* is broader than the energy use of a building. For the specific goal of energy neutrality within a building three experts use the *EPG (energy performance standard buildings)* as best applied methodology. The foundation of this methodology is again the EPC of zero and is directed by the government and corresponds with the in chapter 3.2 described governmental approach.

Another approach, mainly used in residential buildings is *GPR gebouwen* and was mentioned by four experts. However, again this tool goes further than only the energy use of a building houses. A different methodology regarding offices is the use of *energy labels* for office buildings. In this case the energy index determines the energy performance and gives a value between very efficient A, and inefficient G. The values are compared with similar buildings. The method of using *energy labels* has the foundation of the EPC valuation method described in the literature review. And a last approach is the *total cost of ownership* method, in this case energy neutrality is not the foundation but the payback time. It can be used to determine if an implementation is profitable. In practice it is very important that all the techniques that are applied to reach neutrality are profitable and have a payback time of less than 10 years. And in practice due to the economic crisis the payback time is even shorter and is between 3 to 5 years. If this is not the case, the building owners will not invest into making the building energy neutral, but will go for energy saving measures. The *total cost of ownership* method is also used in the literature in the period of ZEB method. Here, the life cycle cost (LCC) is used as a valuation method for determining if the investment is paid back within a certain time range, which corresponds with the *total cost of ownership* method.

TABLE 10 – OPEN CODES, METHODOLOGIES

Open codes 'methodologies'	Mentioned by experts	Corresponds with literature	Corresponding method
1) BREEAM	5	Yes	Legislation
2) GPR	4	Yes	Legislation
3) Total cost of ownership (TCO)	3	Yes	Period of ZEB
4) EPG (Energy performance standard buildings)	3	Yes	Legislation
5) Energy labels	2	Yes	Legislation
6) BREEAM in use	1	Yes	Legislation

The last axial 'influence of the consumer' found in the data is about how the user of the building can be influenced regarding his or her energy use. From the data three open codes were found and are summarized in table 11. Increasing awareness of the energy use by the user is mentioned by four out of six experts. By providing insight in the users' energy use the aim is to confront them on their behaviour and patters and let them see what the effect is of changing their behaviour. Increasing awareness was not found in the literature, but is a good addition for reaching ZEB. Another way is monitoring and is another effective way of lowering the energy use of users and is also part of increasing awareness. For example, in residential buildings awareness is already created with the help of a smart meter which shows the energy use throughout each day. However, T. Smits (2015) points out that this approach has little effect for a long term approach. It only works for a short time and almost 80% of the users will fall back into their old pattern of energy use, it only will work effective for a small group. The reason for this effect is due to the reliability and the cheap price of the current fossil fuels. But, K. Dorst (2015) discusses a different approach where it can be possible. With the aid of a caretaker the energy consumption by the users can be reduced. This involves someone who specifically monitors the electricity and gas consumption of an office. He or she will specifically walks through a building after hours and before holidays to shut down all the appliances that are not used. Only then monitoring will affect the total energy use of a building.

A last approach is automating systems within the building. For example automating the lighting and ventilation within a building. If there is no one around the systems will shut down and only comes on again when there is activity. The result of automation is that energy loss caused by unnecessary usage is prevented. Automation is not specifically called in the literature, but is discussed in the efficiency measures, by optimizing the building envelope and the systems. With the optimizations, the building is fully automated with regarding demand controlled systems and presence detection.

TABLE 11 OPEN CODES – INFLUENCE OF THE USER

Open codes 'influence of the user'	Mentioned by experts	Corresponds with literature	Corresponding method
1) Increasing awareness	4	No	-
2) Automating	4	Yes	Efficiency measures
3) Monitoring	3	No	Efficiency measures

3.6 PROPOSED ZEB DEFINITION

Throughout this literature review and qualitative research, all kinds of different views were pointed out on the concept and methodology of ZEB. In this chapter all that information is processed and used to determine a clear and consistent definition on ZEB. First, an overall definition of ZEB is given and second, a methodology is proposed and boundaries are given.

3.6.1 Zero Energy Building definition

At the heart of the ZEB concept is the idea that buildings can meet all their energy requirements from low-cost, locally available, nonpolluting, renewable sources (Torcellini et al., 2006). As seen previous ZEB can be defined in several ways, depending on the boundary and the metric. After a thorough research regarding ZEB definition and the qualitative research on ZEB, a clear ZEB definition can be proposed. The definition is a combination from all the discussed elements which are important for reaching a clear ZEB. The proposed ZEB definition is stated as:

> 'A building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources from on-site supplies and if necessary off-site supplies'

The fundament of this definition comes from the European parliament and Council of the European Union (2010). However this definition is adjusted, so that off-site supplies are included. As discussed previous, ZEB is difficult to reach for existing building by only using on-site tools, which means that off-site supplies need to be reconsidered as well. This definition is however still broad and can be executed in different ways. To prevent that from happening the next chapters (3.6.2 and 3.6.3) will further explain how to execute this definition and what it entails regarding methodology and boundaries.

3.6.2 ZEB through energy efficient building optimization

[…] *A building where, as a result of the very high level of energy efficiency of the building* […]. The first part in executing the ZEB definition is an implementation of the definition trough energy efficient building optimization. The qualitative research and literature review bring forward that trough automation, the energy use of the users can be lowered and has a significant effect on the overall energy use with a maximum effect of 40% energy reduction. To determine what [...] *a very high level of energy efficiency of the building* [...] is, several boundaries have to be set. The first boundary is the indoor climate boundary based on limitations from chapter 3.4. This means that there are boundaries regarding operative temperature, vertical temperature gradient and maximum airspeed in which occupants can work optimal. These factors have to be reconsidered, because if these values are not reached, the people will not be satisfied and will complain. There are also boundaries regarding building optimization, in chapter 3.4.1 is stated that there is a maximum towards optimization and its effectivity towards energy efficiency. The boundaries can be found in table 12, and are generated from chapter 3.4.

TABLE 12 – BOUNDARIES REGARDING ENERGY EFFICIENCY BUILDING OPTIMIZATION

Indoor climate			
01	Operative temperature	Summer	23 – 26 °C
		Winter	20 – 24 °C
02	Vertical temperature gradient		< 2 °C
03	Maximum airspeed	Summer	0.12 m/s
		Winter	0.10 m/s
Energy efficiency measures			
04	Insulation façade		R_c= 4,0
05	Insulation roof		R_c= 4,0

SOURCE: BOERSTRA, ET AL., 2008; ISOVER, 2014

In conclusion, […] *a very high level of energy efficiency of the building* […] means a building where the employees are satisfied with their indoor climate and the building optimization is done in such a way, that the optimization options have the most impact on lowering the energy loss and energy consumption.

3.6.3 ZEB trough renewable energy supply options

[…] *The overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources from on-site and if necessary off-site supplies* […]. The second part of the ZEB definition includes the use of renewable energy supply options and will be explained in this sub chapter. The literature and experts describe the use of renewable energy all in different ways. All point out that it is necessary to start within the building footprint and the building site to prevent contact and issues with surrounding neighbours. However, it will be difficult to reach ZEB on only site-level due to site circumstances. So first the on-site situation has to be reconsidered, before using off-site renewable energy. Including all this information and the translation of ZEB, the methodology for reaching ZEB through renewable supply options fits best with the hierarchy described by Torcellini (2006). He proposed a hierarchy which starts at building footprint and building site level, if none of these tools can reach ZEB the last option, off-site solutions are included (see table 13).

TABLE 13 – ZEB RENEWABLE ENERGY SUPPLY OPTION HIERARCHY

ZEB Supply-Side Options		Examples
1	Reduce site energy use through low-energy building technologies	Day lighting, high-efficiency HVAC equipment, natural ventilation, etc.
On-Site Supply Options		
2	Use renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building.
3	Use renewable energy sources available at the site	PV, solar hot water and wind located on-site, but not on the building.
Off-Site Supply Options		
4	Use renewable energy sources available off-site to generate energy on site	Biomass that can be imported from off-site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
5	Purchase off-site renewable energy sources	Utility-based wind or other "green" purchasing options.

SOURCE: TORCELLINI (2006)

3.6.4 Methodology definition of Zero Energy Buildings

First a clear definition of ZEB is proposed and explained what it entails. This chapter focuses on the methodology which elaborates the technical and practical elaboration of ZEB. The technical explanation of ZEB is proposed to clarify the exact balance of ZEB. Energy neutrality (ZEB) is reached when there is 0 kWh use of electricity and 0 m^3 use of gas in a year, which is compensated by renewable energy. In short: | export |-| import|≥ 0 in time=1 (years). This means that if a building uses 0 kWh fossil electricity and 0 m^3 fossil gas in a given year and compensated its energy use by renewable energy sources, the building is labelled as energy neutral. The technical explanation has its foundation in the previous discussed methodology names 'metric balance of ZEB'. However, this explanation is not restricted to a specific site-, source-, energy cost- or emission ZEB. It focuses on the overall energy use and loss of the building in the exploitation phase caused by the façade, systems, and users. As discussed, in the Netherlands the metric value of EPC=0 is used, it is the most common used approach in the Netherlands but it does not incorporates the user part of the energy usage in a building (Bouwbesluit online, 2012).

After the technical meaning is explained a framework can be made in order to determine how 0 kWh use of electricity and 0 m^3 use of gas in a year can be reached. This can be done by taking several hierarchical steps figuratively displayed in figure 3, these steps are already formed in chapter 3.6.2 and 3.6.3 and have the foundation based on both Marszal (2014) and Torcellini (2006) their approaches. This approach differs in several aspects with the original version. Marszal (2014) first started with generation on building footprint, however the first step should include the optimization of the building envelop and the system, which together forms the building optimization step. The second difference is the combination of the by Marszal (2014) stated on-site generation from on-site renewables and on-site generation from off-site renewables. This step is for this framework combined in one step – generation of on-site renewable energy.

The first step is optimizing the building with low-energy building technologies. This must be done in an energy efficient why as described in chapter 3.6.2. By optimizing the building trough for example insulation and systems the energy use of the user can be lowered, and the building façade can be optimized. The second step is using renewable energy sources available within the building's footprint (e.g. PV, solar panels etcetera which are located on the building), and taking into account the local climate data.

The third step in the process of making the building energy neutral is using renewable energy sources available on-site. For example, wind energy generation on the site instead of the building. The fourth step entails off-site generation and the building site generates its renewable energy from energy generation plants located outside the project site. A last step in making the building energy neutral is using off-site supply which means the purchase of green energy from the grid. Every building has different characteristics which means that every building needs a different amount of steps to reach ZEB. The combination of the technical value and the framework provides a good methodology on which the previous stated definition can be tested.

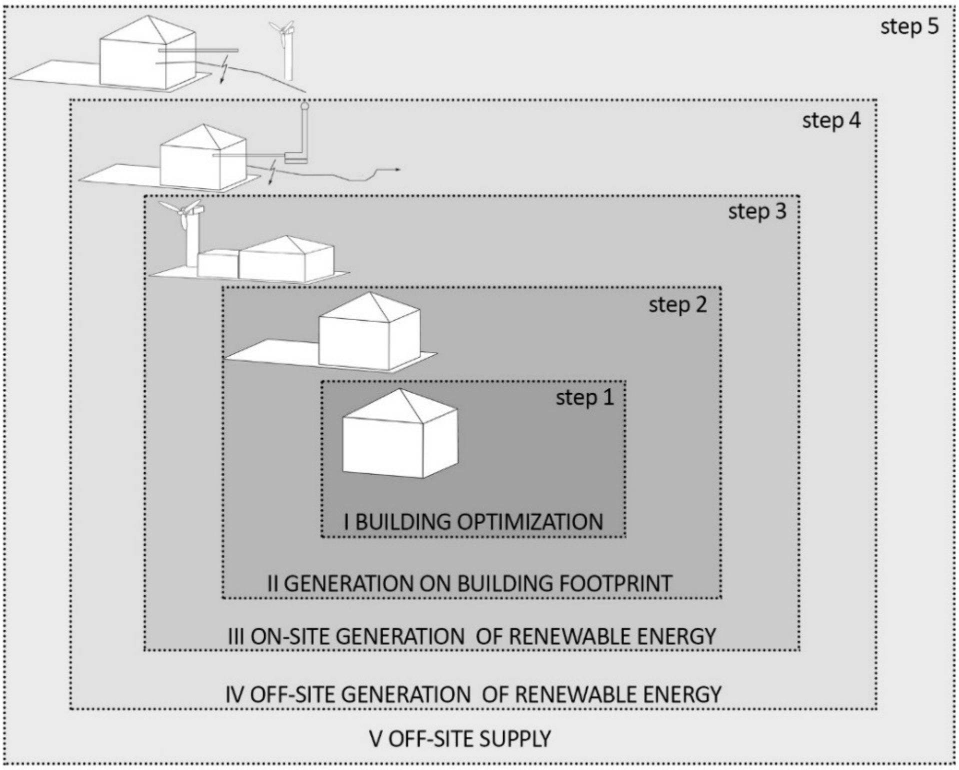

FIGURE 3 – FIGURATIVE REPRESENTATION OF ZERO ENERGY BUILDINGS BY HIERARCHY

3.7 DISCUSSION AND RECOMMENDATION

The boundary of this chapter is the focus on the definition and the methodologies of the concept ZEB in the building industry, and the translation of the requirements which are the foundation of the definition. The definition is defined from the information formulated in the literature review and the qualitative research.

The review of the existing ZEB definitions and the proposals for calculation methodologies indicates the complexity of the concept, lack of common agreement as well as emphasizes the clarified deployment ZEB. In this research two approaches are used to determine a ZEB definition. The first approach, a literature review, is used to understand the different definitions throughout the different literature sources. Due to the time frame, only a small part of the literature is researched. For further research, more sources could be consulted in order to determine more approaches for ZEB. Also, each definition that was proposed in the literature could be used as a foundation for this research, however each approach (e.g. life cycle, metrics etcetera) is used in a different context and cannot be used as an overall definition. Though this doesn’t mean they are wrong.

For the second approach a qualitative research is performed in order to get a clear definition of ZEB in practice. Six experts were interviewed on their view of ZEB, related to the build environment. Only experts of Heijmans were interviewed with an expertise in energy or sustainability. The main foundation of ZEB was distinguished as an EPC of zero based on governmental laws. However, since Heijmans is one part of the build industry further research should focus on consulting more experts form different sources within the build environment. Also it may not be necessary to have a good and clear definition, but to have a value which states if ZEB is reached. Which could mean that only 0 kWh electricity and 0 m3 gas in a year is already enough for determining ZEB. The definition of ZEB can lead to discussions about the implementation and execution and should only be used as a guideline instead of an obligated rule. The definition should incorporate a framework which can be used as one of the approaches for reaching ZEB.

3.8 CONCLUSION

The attention towards the ZEB concept increased during the last years. Many countries already established ZEB within their building energy target. The Netherlands want to reach ZEB before 2020. Among different strategies for decreasing the energy consumption in the building sector, ZEB have the promising potential to significantly reduce the energy use and as well to increase the overall share of renewable energy. However, due to the different translations of ZEB and explanations on when ZEB is reached, there is a need for a commonly agreed ZEB definition framework and a robust ‘zero’ calculation methodology. This framework should allow for a variety of solution sets and not focus only on specific solution sets.

This paper presented a literature review of ZEB definitions, a qualitative research and proposed energy calculation methodologies for ZEB. Throughout the paper two approaches are used in order to determine ZEB definition. In the first approach a literature review, the paper identified and presented a set of parameters that differ between ZEB definitions and which should be elaborated before defining a harmonized ZEB understanding. In this review five different approaches towards ZEB were identified and defined as: national code of ZEB, metric balance of ZEB, ZEB by climate data, period of ZEB and as last on-site or off-site ZEB, all further explained in the previous chapters. The second approach for identifying a definition of

ZEB was a qualitative research, which was performed with 6 experts in the field of energy and sustainability. This research was performed in order to understand the practical experience of ZEB. By combining the two approaches a good and clear definition towards ZEB could be made and is stated as 'A building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources from on-site supplies and if necessary also off-site supplies'. Besides a good and clear definition for ZEB within existing buildings, also requirements are necessary to include to determine the boundaries of ZEB. The requirements can be defined as energy efficacy measures and indoor climate requirements.

From this information a technical value could be identified for reaching ZEB and is defined as the use of 0 kWh electricity and 0 m^3 gas in a year. In short: | export |-| import|≥ 0 in time=1 (years), which corresponds with a metric balance. This means that if a building produces 0 kWh and 0 m^3 gas in a given year, the building is labelled as energy neutral. This definition can be used as an overall translation of ZEB and can be used for the next chapter to test if ZEB is reached. Furthermore a framework is stated on how to reach the proposed definition, with its foundation base on the approach of Marszal (2014) and Torcellini (2006). Several hierarchical steps could be identified as: building optimization, generation on building footprint, on-site generation from on-site renewables, off-site generation and as last off-site supply. Together, the technical value and the framework provide methodology for determining if the definition of ZEB is reached.

CHAPTER 4 – NAVIGATING TOWARDS ENERGY NEUTRALITY: A SYSTEM DYNAMICS APPROACH

ABSTRACT

How can office buildings be made energy neutral to limit global warming and fossil fuel exhaustion? This chapter tries to give insight in this problem by using a bottom-up approach to see if it possible to reach energy neutrality in office buildings. System Dynamics (SD) is used to understand the current technologies and combinations. SD is specifically helpful in this situation to understand system behaviour by looking specific at the interrelations between the subsystems instead of looking at them as an isolation of each subsystem which is needed to reach energy neutrality. To understand the behaviour, a causal loop is made and the sub systems are explained. A case study is used to see whether or not neutrality can be reached and to test the model. The exact validation is done through the case study by comparing the results of a different study and using experts to see if the results show a realistic effect. The case study shows that it is possible to reach energy neutrality and shows what steps need to be taken in order to actually achieve neutrality.

KEYWORDS: ZERO ENERGY BUILDINGS, ENERGY EFFICIENCY, RENEWABLE ENERGY GENERATION, SYSTEM DYNAMICS, CASE STUDY

4.1 INTRODUCTION

4.1.1 Problem definition

Energy use, and the associated carbon dioxide emission has been rising rapidly over the past few decades. The main consumers are the developed countries. The consequences of the continuing growth of energy use are potentially catastrophic. The developed countries must improve their energy efficacy to ensure that the problem is brought under control. As for most developed countries, the energy system in the Netherlands is largely driven by the combustion of fossil fuels. In 2009, natural gas is supplying about 45.0% of the total primary fuels used in the Netherlands, followed by liquid fuels (38.0%) and solid fossil fuels (9.6%). The contribution of no fossil fuels, including renewable and waste streams is rather limited (van der Maas, et al., 2011). The built environment accounts for approximately 35% of the total Dutch energy consumption. More than half of this part is used in commercial buildings such as schools and offices (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012).

Despite impressive technical innovations it is still not yet managed in the Netherlands and elsewhere in Europe to make existing buildings on a large scale energy neutral (GEN, Idema and de Koning, 2014). This raises the question if it is possible to make existing buildings energy neutral and if so, how? This chapter addresses the complex structure of Zero Energy Buildings in an attempt to answer the following main research questions (RQs) ‘*what is the feasibility of energy neutrality in existing office buildings with current instruments*’. As part of answering that question, this chapter addresses the tools that are available on the market for energy reduction and energy generation and how these techniques can be combined to make a model and show with the help of a case study if neutrality is possible.

This chapter starts in chapter 4.2 with the explanation of the used method and why this method is used for this research problem. Chapter 4.3 gives a thorough explanation of the model that is made and which steps are taken. In chapter 4.4 a case study is used to see if the model works and chapter 4.5 shows the results resulting from the case study and the model. Chapter 4.6 describes the validation of the model. This chapter ends with a discussion and conclusion.

4.2.1 Research objectives

The aim of this chapter is to identify the possibilities to make office buildings energy-neutral and providing insight into how a sustainable energy-neutral office might look like. The previous chapter focused on the definition on when a building is energy neutral. This definition and methodology is the foundation of the model which is discussed in this chapter. The definition that is used for zero energy buildings is *'a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources from on-site supplies and if necessary off-site supplies'.* The methodology for determining ZEB is stated as a metric of balance which states that if a building produces 0 kWh electricity and 0 m^3 gas in a given year, the building is labelled as energy neutral. The steps for reaching neutrality are predefined as (1) building optimization, (2), generation on building footprint, (3) on-site generation of renewable energy, (4) off-site generation of renewable energy and (5) off-site supply.

This research provides insight on how to lower the CO_2 emission by making existing nonresidential buildings energy neutral, and in specific office buildings. This can be done by identifying the best technical solutions to make existing buildings energy neutral, and making a standard model which can be applied on a larger scale through a bottom-up approach.

The reason for choosing a bottom-up approach is that until this day, it is not possible to make existing buildings on a large scale energy neutral (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012). The objective is pursued by (1) determining what instruments are available for energy saving, by (2) gathering the information from the tools and translating them into usable information for the model and (3) developing a tool that helps assessing the instruments to determine the optimal solution.

4.2 METHOD

4.2.1 System dynamics, a definition

System Dynamics (SD) is a methodology and mathematical modelling technique for framing, understanding and discussing complex systems (Sterman, 2000). System dynamics is a cross-discipline that developed on the basis of feedback control theory, decision theory, simulation technology and computer application technology. The modelling process contains systematic reasoning. It is a process of learning, investigating and researching (William, 2009). When reviewing different scientific articles that research sustainable development with support of System Dynamics, a common pattern can be perceived in the research approach. This pattern is shown in figure 4 and consists of 5 basic steps, further explained in the glossary (see chapter 2).

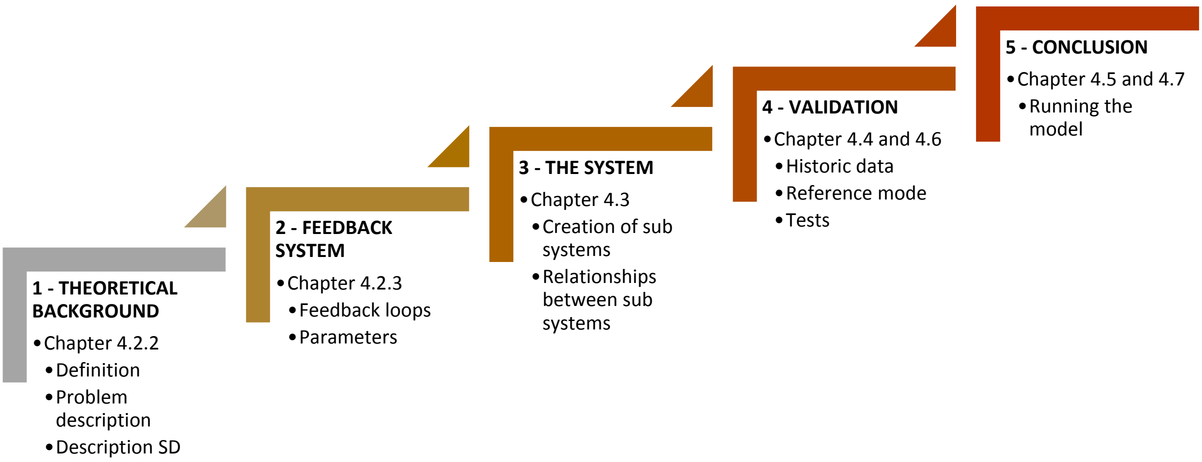

FIGURE 4 – STEPS IN SYSTEM DYNAMICS

4.2.2 System dynamics and sustainable redevelopment

The interest in urban sustainability has grown in attraction by researchers over the last ten years tremendously (Naess (2001), Zavadskas et al., (2004) and Hjorth et al., (2006)). In order to understand the source and the solutions to modern problems such as urban sustainability and redevelopment, linear and mechanistic thinking must give way to nonlinear and organic thinking, more commonly referred to as systems thinking. SD is suitable for the evaluation of sustainable urban redevelopment due to 'its feedback structure and capability to function under different parameter settings and initial inputs. System Dynamics is a tool which can be used to either predict the future or understand system behaviour. Due to the research question the focus of this research is to gain insight in system behaviour.

In the case of this research, the main research problem is how energy neutrality can be reached within the existing office building stock. The dynamic behaviour of the technologies, the building specification and the people within the office buildings rises the need for a feedback structure that functions under different parameters settings and initial inputs. This approach is used to find and understand the conditions under which the system will evolve in what direction. SD looks specific at the interrelations between the subsystems instead of looking at them as an isolation of each subsystem. This chapter builds the causal loop diagram and stock-flow diagram based on the software platform Vensim (Ventana Systems, inc., 1989-2012).

4.2.3 The causal loop

In framing the scope of an SD model, the first step is the construction of a Causal Loop Diagram (CLD). The CLD shows the feedback loops among key variables of the model, with a positive (+) or negative (−) sign placed beside the arrowhead that represents the relationship between variables (Ford, 2010). The loop itself can either be a balanced (B) loop or a reinforced loop (R). If the key variables increases the effect of the next variables the loop is reinforced. If the variables in the loop counteracts the next variables by decreasing the effect the loop is called a balancing loop. Figure 5 shows the causal loop for modelling energy use and ZEB. From this figure the following loops are identified: *innovation loop, quality loop, environmental loop, energy loop, ZEB loop, renewable energy ZEB loop* and *impact on innovation loop*. The causal loop goes further than the research question, but the different loops need to be pointed out to understand what the other variables are which influence the decision to make a building energy neutral. The main focus is to answer the research question in this research, this means for the modelling of the research problem that the quality loop is worked out but for further research the other loops can be inserted into the model as well, however this goes out of bound for this research, the explanation of the other loops in the causal loop can be found in appendix 8.

Quality loop – the energy use of a building is depended on the quality of the building. If the quality of the building is low (due to age, old systems etcetera) more energy is needed. If people have to use too much energy they will think about the optimization (e.g. systems, insulation etcetera) of the building to reduce the energy use. If the optimization is done, the quality of the building will be high again and people will use less energy. This process can be described as a balancing loop.

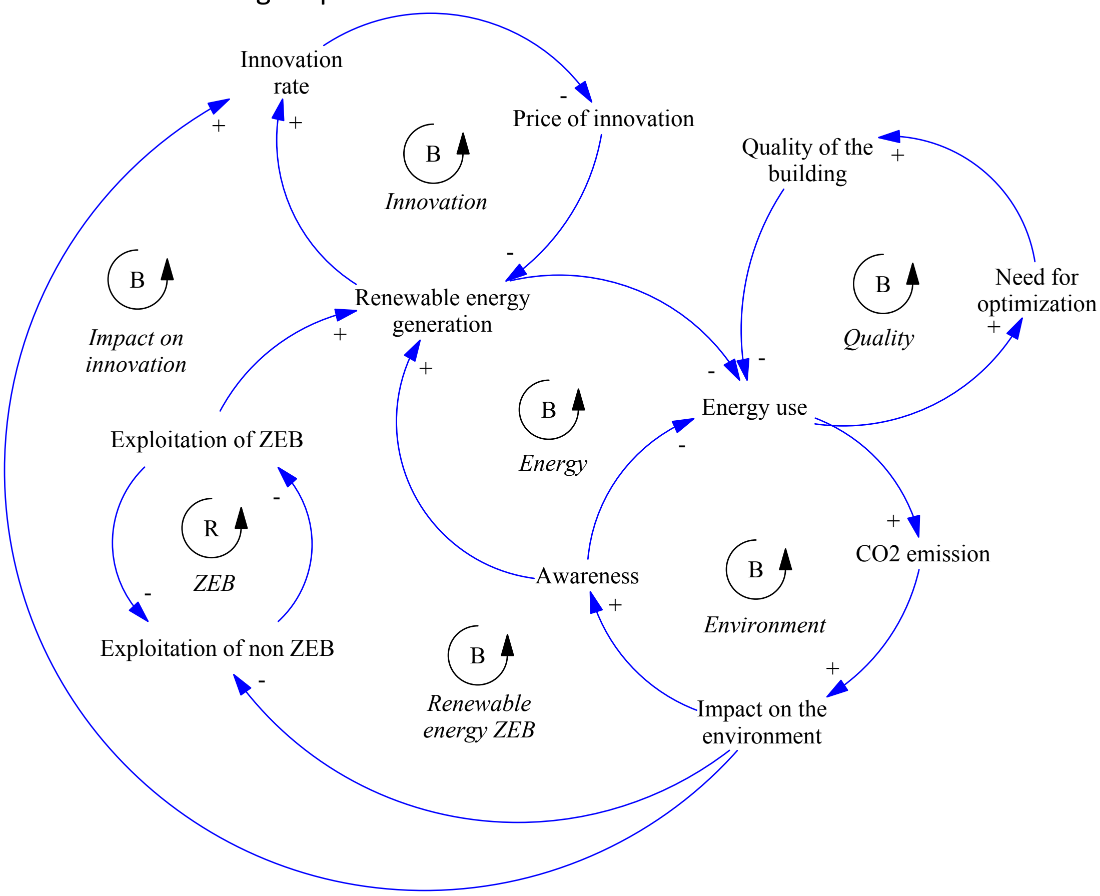

FIGURE 5 – THE CAUSAL LOOP DIAGRAM

4.3 MODEL

4.3.1 Model description

In chapter 3, the overall definition of ZEB is described as 'a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources from on-site supplies and if necessary off-site supplies'. From this foundation, 5 steps have to be taken in order to reach the 0 kWh electricity and 0 m^3 gas in a given year (further explanation see chapter 3.6). These five steps include 1) building optimization, 2) generation on building footprint, 3) energy generation on-site, 4) energy generation off-site and as last 5) off-site supply. These five steps are modelled in Vensim and can be seen in appendix 9. Each section is discussed next in separate sub-chapters. As can be seen in appendix 9, there is a distinction between red, green and black variables. The red variables are empty constants which need to be filled in for each building using the user interface, explained in chapter 4.3.8. The black variables (either auxiliary, constants or levels) are already filled in and are used for the dynamic modelling. The green auxiliary variables are the end result of each sub system. Appendix 10 provides an overview of the information that is inserted into the model and the formulas of each variable.

4.3.2 Energy improvement tools

For the model there is information needed about the energy improvement tools, based on the previous discusses steps. To determine what current tools are available on the market, the literature study in the previous chapter is used. Torcellini (2006) addresses the main techniques that are available on the market, described in table 13 chapter 3. Of course, currently there are also other techniques available on the Dutch market. To determine what those techniques are, several documents are consulted such as (Heijmans, 2015), SenterNovem (2015) and the RVO (2012) to see what techniques are used for energy reduction, building optimization and renewable energy generation. An overview of the used techniques are shown in table 14.

After a thorough research the techniques for lowering the fossil energy use is summarized in appendix 12. Appendix 12 is build up based on the different tools that are available on the market and the sources discusses above. The techniques are explained by their energy reduction or generation potential, their cost reduction after investment, the investment costs, the payback time and the reason for either choosing the technique yes or no.

The main source for the investment cost of the techniques is the technische unie (2015) (English: technical union). All techniques are checked with more than one source to check its accuracy. As can be seen in the appendix, there are several options available of each sub system. To determine the optimal technique, several boundaries have to be set. The first boundary is the energy efficiency boundary, which is explained in chapter 3.6.2. For example if there are products which have an Rc value of 1.7, 4 and 2.5 for building envelope insulation, then the optimal value is stated as a product which has an Rc of 4. In that case the product with the same value is the best choice and will be used in the model. The second boundary is the payback time, as is mentioned in chapter 3.5.4 by the experts. If a product has a payback time between 5-10 years it can be used, if the technology has a higher payback time of 10 years than the subsystem of the technology will not be modelled at this moment. If it is still not set on which product to choose, the last two boundaries are set as the largest cost reduction and the lowest pay-back time. Appendix 12 points out for each element why it is chosen yes or no. And finally, in the case of system optimization there is chosen due to a limited time frame to optimise the systems with the variables of the building envelope and not the variables which are not part of the building envelope (e.g. not building related electronica etcetera). To include these variables in the model, is a study itself. However, to make the building energy neutral, the energy flows of the electronica are a part of the electricity demand of the building. The compensation of the fossil use will be generated with the help of the generation of renewable energy.

In the next sub chapters from 4.3.3 to 4.3.7, the main technologies are discussed. The aim is to explain how the tools are modelled. The main variables for modelling the technologies are:

- 'When can a technology be used?'
- 'What is the reduction rate in energy of each technology?'
- 'Is the reduction of the energy use depended on other elements?'
- 'Differs the reduction of the energy use per month or not?'

Table 14 provides an overview of what technology has what effect on the heat demand, cooling demand or electricity demand, appendix 11 explains what the exact connection is between each technology.

TABLE 14 – DEMAND REDUCTION AND EFFICIENT CONVERSION OF TECHNOLOGIES

	DEMAND REDUCTION	EFFICIENT CONVERSION		
		GAS	ELECTRICITY	GENERATION
Heat demand	• Insulation • Efficient systems	• HR boiler • HRe boiler • Biomass boiler • Gas heating pump • Heat cold storage	• Heating pump	• Sun boiler
Cold demand	• Sun shading • Efficient systems	• Absorption	• Airco heating pump • Heat cold storage	• Cogeneration • Biogas
Electricity demand	• Efficient	• HRe boiler • Micro cogeneration		• Solar • Wind

4.3.2 Initial situation

The initial situation is the constant level of the building over a year. The energy use of an office building can be divided into two energy flows existing of electricity use and gas use, see figure 6. The electricity use of a building exists of cooling, DWH, moistening, lighting, office equipment (e.g. laptops, printers etcetera), pumps and ventilation. The heating system and equipment are responsible for the gas demand in the building. If there is enough information available of the building, then the exact amount of electricity per system can be inserted into the model. If that is not the case, indicators can be used to determine what the average energy is per system. The variables 'usage of fossil electricity' (e.g. 0 kWh electricity) and 'usage of fossil gas' (e.g. 0 m^3 gas) show if energy neutrality is reached yes or no. They show how the renewable energy sources influence the fossil energy demand.

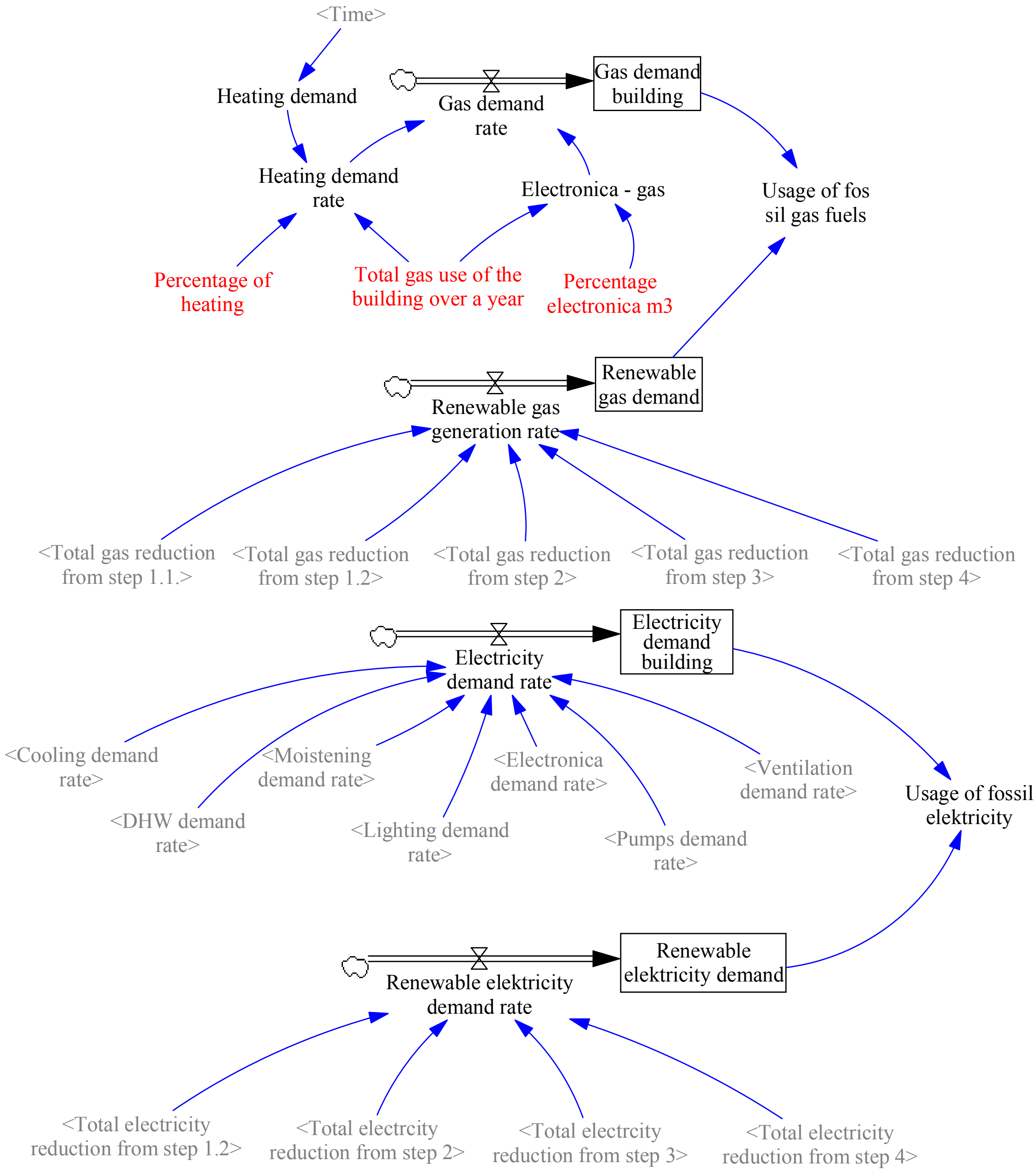

FIGURE 6 – INITIAL SITUATION

To determine what the exact flows are over a year from electricity and gas, several curves have to be modelled such as the cooling curve, heating curve, lighting curve etc. figure 7 shows the overview of how the curves are inserted into the model. For the exact explanation of how the curves are created see appendix 13.

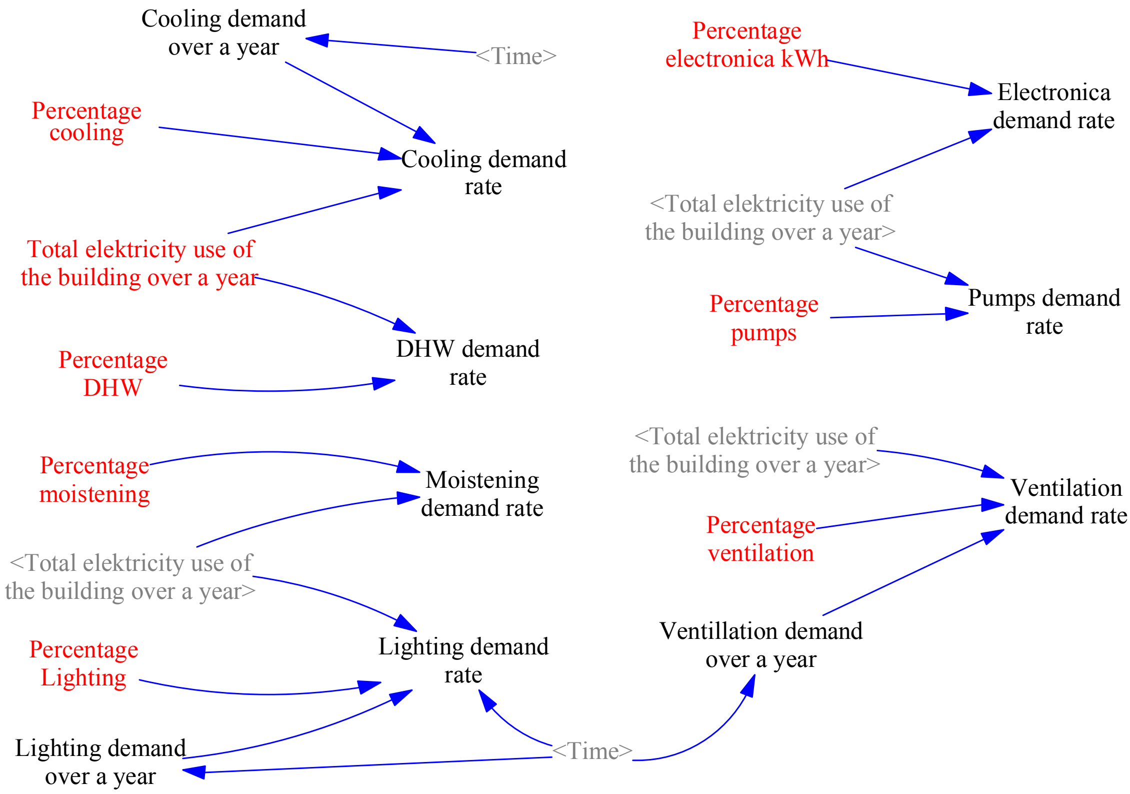

FIGURE 7 – DEMAND CURVES

4.3.3 Building optimization

Facades, windows, floors, roofs and doors are all constructions. The insulation of a construction determines for a significant part how much heat from the building can escape to the outside, as explained in chapter 3.4.1 energy efficiency measures. A building with a high insulation value has less heating energy needed, but the cooling requirements can thus be increased. Building optimization can be divided into two steps. Step 1.1 building envelope optimization and step 1.2 system optimization. The first sub step 1.1 building optimization can be divided into four sub optimizations; cavity wall insulation, roof insulation, floor insulation and HR+ insulation as can be seen in appendix 9.

The insulation options provide for a reduction of the energy loss caused by the installation. The first optimization is building envelope insulation (step 1.1.1), see figure 8. The best method for building envelope insulation is cavity wall insulation. Outside wall insulation is in many cases not preferable due to appearance change. The average value of the reduction rate per square meters is 8 m^3 gas per m^2 per year (Milieu centraal, Gevelisolatie buitenkant, 2015). This average value various over the year depended on the average outside temperature. In the winter and summer the effect is bigger than in the spring and autumn. With the help of a look-up this situation is modelled. The look-up is based on the variation on the outside temperature (as can be seen in table 15) times the average reduction rate. This approach is also used for the look-ups for steps 1.1.2 – 1.1.4.

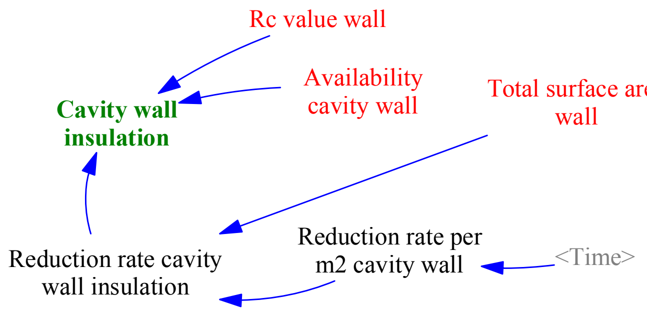

FIGURE 8 – SUB VARIABLE, CAVITY WALL INSULATION

TABLE 15 – AVERAGE TEMPERATURE, NETHERLANDS

Month	Average temperature (°C)	Variation (%)
January	5.7	51
February	6.5	44
March	8.4	28
April	12.1	4
May	13.2	13
June	16.2	39
July	19.8	69
August	16.1	38
September	15.9	36
October	13.4	15
November	8.2	30
December	4.8	59
Average temperature	11.7 °C	

SOURCE: (KNMI, 2014)

The second step is roof insulation (step 1.1.2) see figure 9. The average value of the reduction rate of roof insulation differs if the roof is flat or sloping. For a sloping roof an average value of 9 m^3 gas per m^2 per year for flat roofs that is 10 m^3 gas per m^2 per year. Again the average per month is based on table 15. The red variables can be filled in to determine what roof is available and how large the roof area is.

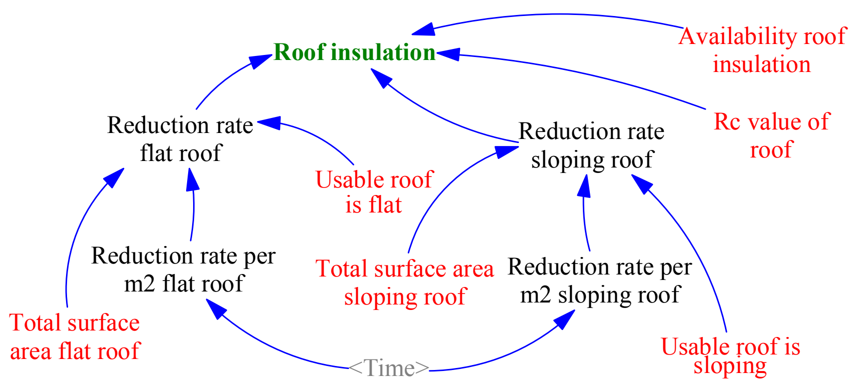

FIGURE 9 – SUB VARIABLE, ROOF INSULATION

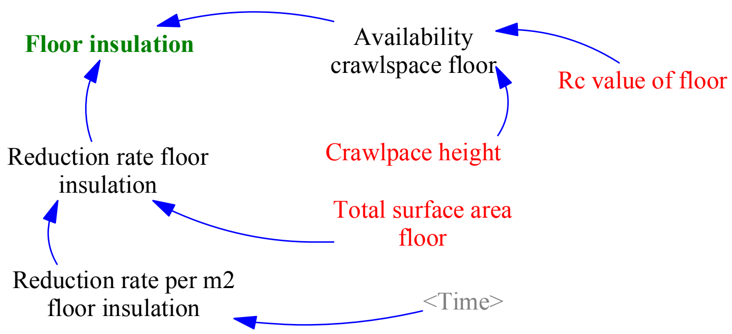

FIGURE 10 – SUB VARIABLE, ROOF INSULATION

The third step is floor insulation (step 1.1.3), see figure 10. Insulation of the floor can only be done if there is a crawls pace below the floor and the crawls pace is more than 35 centimetres. If these criteria are met the reduction rate is 5.7 m^3 gas per m^2 per year. The last step in building optimization is window insulation (step 1.1.4), see figure 11. In this case there is chosen for modelling HR+ glazing, with HR+ glazing the boundary of an Rc below 1.90 is met and has the best cost/benefit ratio. The reduction rate of single glazing and double glazing in comparison with HR+ glazing is for single glazing general 20.80 m^3 gas per m^2 window, and for double glazing 4.5 m^3 gas per m^2 window. If the windows have already a HR+ or more glazing than the effect will be zero.

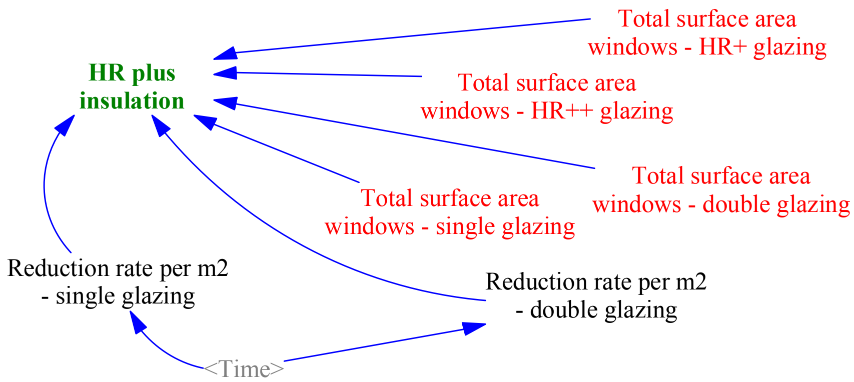

FIGURE 11 – SUB VARIABLE, WINDOW INSULATION

After the building insulation step has taken place, the second phase – the optimization of the systems – can take place. The optimization of the systems can be sub categorized into 7 sub-systems; 1) ventilation systems, 2) heating systems, 3) cooling systems, 4) lighting, and as last 5) sun shading as can be seen in the appendix 9.

The first step in system optimization (1.2.1) is the optimization of the ventilation systems, see figure 12. Ventilation is necessary for a healthy building. Besides supply of fresh air, ventilation air can also be used to heat the building, cooling or moistening. Ventilation can be done through natural ventilation e.g. opening windows or vents places. Additionally, fans can be used, then one speaks of a mechanical ventilation system. Where there is both mechanical supply and drain, then there is heat recovery possible. The heat from the exhaust air can be used to preheat supply air. The building code and the European norms (NEN-codes) based on chapter 3.4.2 indoor climate, show that in office buildings the ventilation capacity has to be 6.5 dm^3/s per person (BRIS, 2014), this corresponds with 45 m^3/h per person. So for each persons that is present in the building the ventilation system has to produce 45 m^3/h ventilation per person.

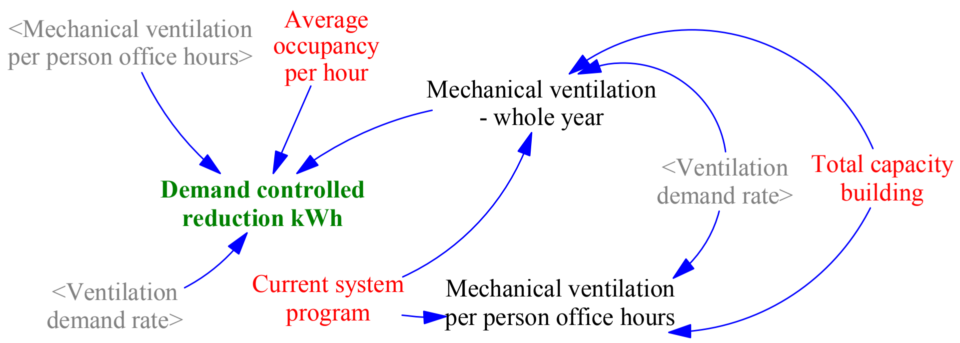

FIGURE 12 – SUB VARIABLE, VENTILATION SYSTEM

For energy savings measures the best installation system is one with a presence detection which determines at what percentage of its total capacity the system has to ventilate. This means that the ventilation system isn't active on its full capacity during office hours, but is active when there are people present in the building. In general, the office building is not occupied for 100% of its capacity (S&P, 2014). A normal ventilation system works either 24 hours a day throughout the whole year or only during office hours. The energy savings are during the hours that the office building is not full and the ventilation system does not have to ventilate its total capacity. To determine the average occupancy of the building, the information about the total capacity of the building is needed and the overview of the people present in the building per hour to determine the average people per day throughout a year. Table 16 shows the average occupancy of a building office during office hours. This table is the foundation to determine what the average ventilation demand is per day and to calculate it in terms of months.

TABLE 16 – PEOPLE PRESENT IN OFFICE BUILDINGS

Opening hours [h]	Percentage present of total [%]
6-8	20
8-9	30
9-10	65
10-11	95
11-12	80
12-13	60
13-14	20
14-15	20
15-16	60
16-17	60
17-18	60
18-19	30
19-20	20
20-22	10

SOURCE: S&P (2014)

For step 1.2.2 the heating situation is discussed, see figure 13. In order to heat the rooms in the building, there is a heat source needed. Furthermore, the need to heat to the spaces are distributed, where it by means of, for example, radiators, issued convectors or vents. First an analysis of the current situation is needed to determine what the effect of a new system is. Therefore the information of the current system(s) is needed such as the power and the type of system. As mentioned in subchapter 3.4.2, there are provisions regarding the heat- and cold load in the OHS regulation (Dutch Arboregelingen). This chapter stated that the average temperature in an office building has to be kept between 20-24 degrees. To keep the office space at an average temperature of 22 degrees there is 85 watt per m^3 needed for heating (CV ketel capaciteit of vermogen berekenen, 2014).

Also, the heating hours per year are needed to model a realistic view of when the heating systems are running during a year. During a year, the heating systems will be used from October through April. The heating systems will be used 21 workdays per month existing of 8 work hours and 3 outside office hours a day. Together, this will give an average of 504 heating hours from October till April (Polders klimaat beheersing, 2014), see also appendix 13, the demand curve of heating. As can be seen in appendix 12, the optimal energy efficient measure regarding heating systems is an HR107 installation, which has the best gas use / heat loss ratio. For the calculation of the power output and the gas use of an HR107 system the calorific value of natural gas in the Netherlands is needed and is stated as 31.650 kJ/m^3, also 3.600 kJ is the same as 1 kWh. With this information the combustion of 1 m^3 gas is then equal to = (1.07 × 31.650 kJ)/(3600 kJ) = 9.407 kWh power output (ISSO, 2015). To determine what the effect is of an HR107 on the current system the efficiency of all the available boilers are needed. The efficiency of a CV boiler is 75%, a VR boiler 80% and an HR107 boiler has an efficiency of 107% (Milieu centraal, 2014). The difference between efficiency is used to determine the gas reduction of changing the system towards a HR107 boiler. Of course the reduction in gas use by the heating system can be done in other ways such as the generation of heating pumps and a micro cogeneration, these will be discussed in chapter 4.3.5. The relation and effects the systems have on each other will also be further discussed in chapter 4.3.5 and appendix 10.

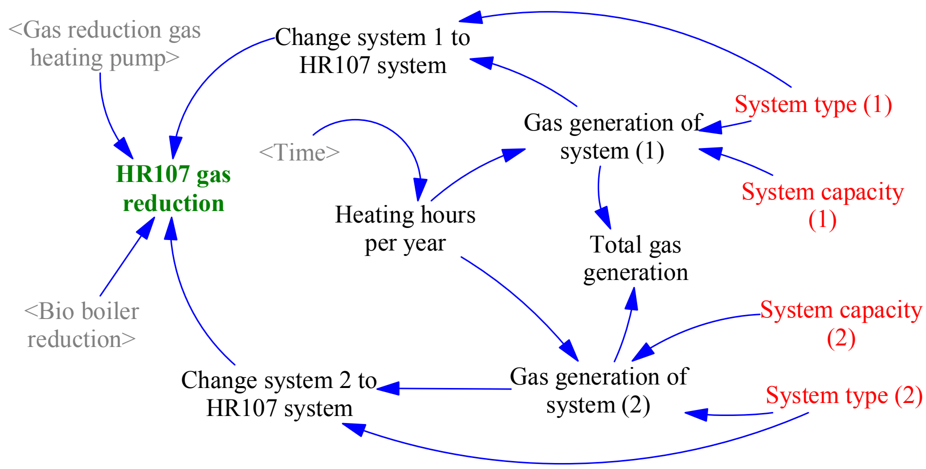

FIGURE 13 – SUB VARIABLE, HR107 GAS REDUCTION

Step 3 for the optimization of the installation is the cooling systems (step 1.2.3), see figure 14. In many office buildings cooling is present to prevent the building becoming too hot in the summer. As with space heating, it must be raised from the cold for space cooling and transported to the cooled areas. As can be seen in the appendix 12, the best option regarding cooling optimization is dew point cooling. The difference with compression cooling is that the COP value (Coefficient of Performance) of dew point cooling is much higher than compression cooling. This means for dew point cooling (with a COP of 18) that for each electricity use the dew point cooling provides 18 times the supplied cool air. However, the COP is a theoretical efficiency, to get a real representation of the reality the COP has to be lowered with 0.7 (the seasonal performance factor). To determine what the current capacity is of the cooling system the COP values and the total electricity use caused by cooling are used to count back to its needed capacity and with that the reduction rate by using a dew point cooling system (Lobregt and van der Stoel, 2009).

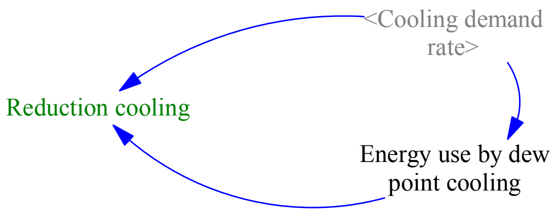

FIGURE 14 – SUB VARIABLE, REDUCTION COOLING

Step 4 is the reduction trough lighting (step 1.2.4), see figure 15. The reduction of lighting can be done in three steps. The first step is by changing the old lighting to sustainable lighting whose power consumption is 3 watt per square meters (Phillips, 2010). The second step is installing daylight depended lighting control which causes for a 30% energy reduction (ISSO, 2015) of the energy use by lighting. And the last step, presence detection which causes for a 30% energy reduction of the energy use by lighting (ISSO, 2015). The lighting is depended on the amount of operating hours per year which is approximately 2400 (van der Laan, 2010), see also appendix 13 lighting demand curve. In the end, the reduction is calculated by multiplying the operating hour's times the power of the lighting per fixture times the amount of fixtures minus the optimizations (e.g. new fixtures, presence detection and daylight dependent lighting).

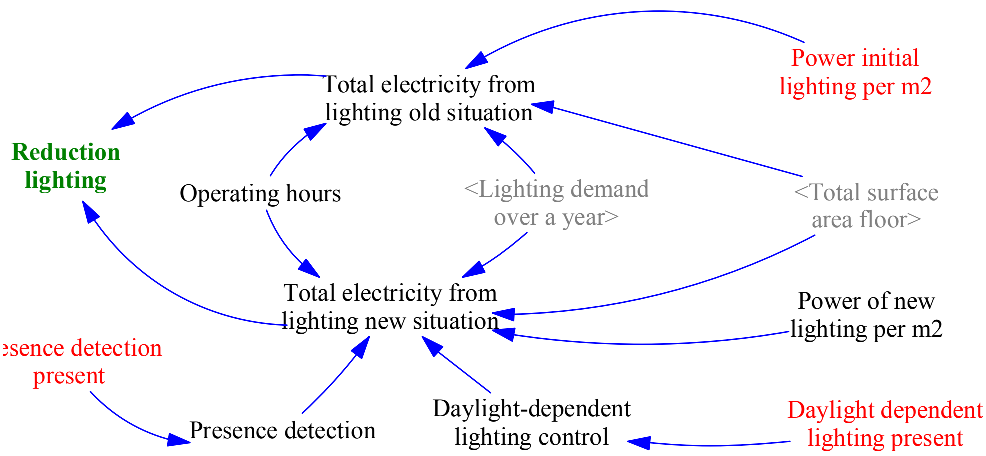

FIGURE 15 – SUB VARIABLE, REDUCTION LIGHTING

The last adjustable system is the sun shading system, see figure 16. Direct sunlight has, as measured on a vertical plane, a power of about 600 to 1,000 W/m^2. Diffuse sunlight knows a power of approximately 50 to 150 W/m^2. On an annual basis falls at least 400 kWh per m^2 window diffused light. To cool this away, at least 200 kWh of electricity per m^2 window is required. For direct sunlight, the values doubles. For direct lighting, at least 800 kWh per m2 window needs to be cooled away by using at least 400 kWh of electricity per m^2 window. (TNO 2011).

There are several techniques to prevent diffuse and direct sunlight from entering through the windows, by using sun shading. It is possible to apply sun shading on the outside, inside or a combination of the two. TNO (2011) did a thorough research about the energy reduction and the combination with sun shading. Bakker, Zonneveldt and van Oeffelen (2011) determined that in an office building the best sun shading system is automated outside screens (350 W/m^2) without inside manual screens. The automated screens are used during the summer situation and the manual screens were used during the winter situation. This gives a 23.1% primary energy reduction compared with no sun shading at all. The result of this type of sun shading is that the primary energy use of lighting goes up, because when the screens are down extra lighting is needed. But, the effect is that less cooling is needed from the cooling systems. The effect of applying outside screens on the cooling, heating and lighting differs per initial situation, the differences can be found in table 17.

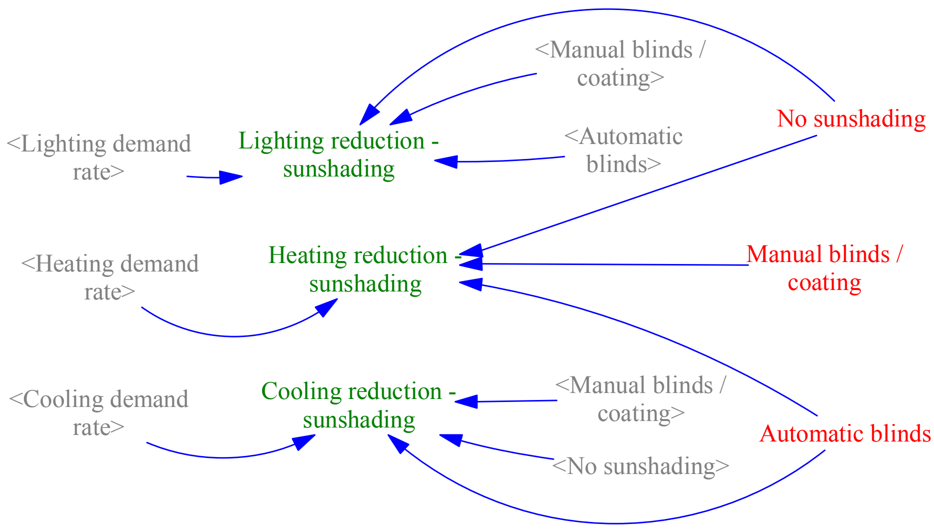

FIGURE 16 – SUB VARIABLE, REDUCTION SUN SHADING

TABLE 17 – HEATING, COOLING AND LIGHTING REDUCTION OF AUTOMATIC SCREENS

	No sun shading towards automatic screens energy reduction	Manual screens / coating towards automatic screens energy reduction
Heating	- 37.5 %	- 8.3 %
Cooling	+ 60.0 %	+ 31.2 %
Lighting	- 37.5 %	- 31.2 %

SOURCE: TNO (2011)

4.3.4 Generation on building footprint

After the optimization of the buildings systems, it is possible that the building is not yet energy neutral. The second step in the process of making the building energy neutral is generation of sustainable energy on the building footprint. Generation on the building footprint can be done with three technologies; 1) solar panels on the roof, 2) wind turbines on the roof, 3) solar hot water and as last 4) micro cogeneration.

The first technology – solar panels – can be modelled as shown in figure 17. The amount of solar panels on the roof can be determined by the type of roof, orientation and the total area of the roof. If the roof is oriented on the south, south-east or south-west solar panels can be applied. In the case of a sloping roof, the angle has to be between 20 to 60 degrees to be useful for solar panels. The optimal angle is 35 degrees, by all other angels between 20 to 60 degrees the generation is 5% less than with an angle of 35 degrees (Zonne-energie gids, 2015). Buildings with a roof on the east or west have a generation of 85% of the yearly of the amount of the collected light.

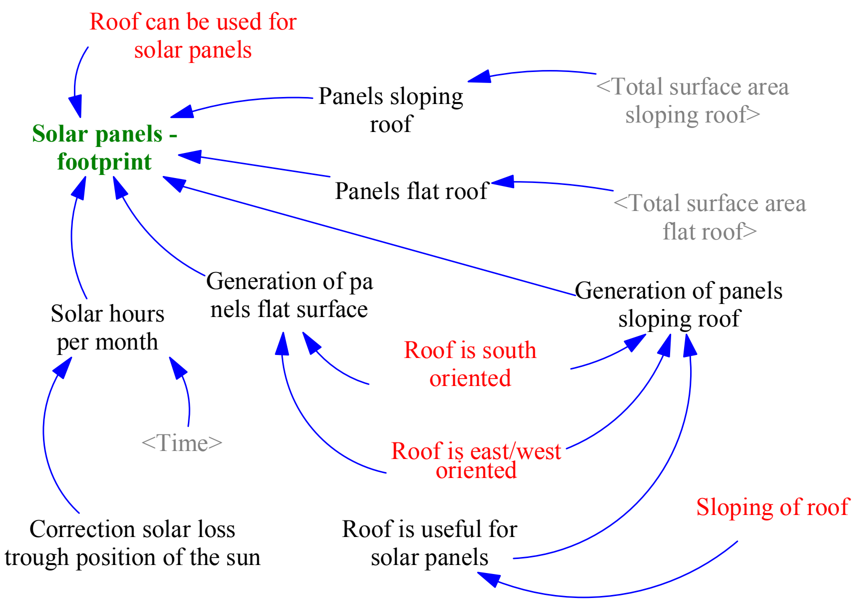

FIGURE 17 – SUB VARIABLE, SOLAR PANELS, FOOTPRINT

If a building has a sloping roof, then there is 1.5 m^2 roof needed per panel, for flat roofs this is 2.5 m2 due to shadow space between each panel (Solsolutions, 2015). To determine how many sunshine hours there are in the Netherlands the database of the KNMI (the Dutch weather station) is consulted (KNMI, Zonuren calculator , 2014). In the Netherlands there is an average of 1000 solar hours per year. Table 18 shows the amount of solar hours per month in the reference year of 2014. In general, there are 1000 solar hours per year, but due to shadow and the changing of the position of the sun, the average generation is 85% per panel. This means that the average generation per panel is 1000 x 0.85 x generation by orientation. Table 19 shows the generation of each panel by orientation and angle, based on the previous discusses values. However, it is possible that solar panels are not possible within the building footprint due to construction reasons or other reasons, in that case the sub system will be zero.

TABLE 18 – AMOUNT OF SOLAR HOURS IN 2014

Month	Solar hours
January	20.01
February	35.78
March	92.66
April	118.67
May	140.84
June	165.68
July	156.21
August	124.55
September	96.02
October	48.05
November	27.06
December	15.19
Total solar hours	1040.72

SOURCE:KNMI, ZONUREN CALCULATOR, 2014

TABLE 19 – GENERATION BY ORIENTATION AND ANGLE

	Orientation	
Angle of the panel	South	East/ west
35° - 36°	0.85	0.73
20° - 34°	0.81	0.68
36° - 60°	0.81	0.68
< 20°, > 60°	0	0

The second technology which can be used for the building footprint are wind turbines on the roof. However, due to a pay-back time of more than 15 years it is not profitable at this moment to model wind turbines on the roof (see appendix 12). If the wind turbines have decreased in price and increased in generation in the next years, this element can be modelled within the Vensim model.

The third technology is implementing a solar hot water system. For the preparation of hot water all kinds of hot water generations can be used. In general the systems used for hot water are electric boilers with several tap points. As can be seen in appendix 12 is that the payback time of a sun heating system is above the 10 years. This means that the investment in a solar hot water system is not yet profitable. This means that at this moment, the solar hot water system is not modelled due to a high payback time. However, it is still possible to generate energy for the reduction of the electric boiler for the hot water. Another technology is a heating pump, this will be discussed in the next subchapter 4.3.5.

The last technology which can be used for the generation of energy is a HRe system, which is a small micro cogeneration system. A high-efficiency boiler (or micro-cogeneration) generates electricity as well as heat. If the boiler is on it doesn't only heat the water for heating and hot water but also generates electricity. The system of micro-cogeneration can be seen in figure 18. It is only profitable to use a HRe boiler with a gas use above 2.000 m^3 (Duurzaam MKB, 2014). Besides the gas use, a HRe boiler is the most profitable in a building with a low insulation level. This means that is sometimes profitable to not insulate the building and install a HRe boiler, this is calculated in the model by calculating the payback time, if it is higher than 10 years than this system will go out. The HRe system uses more gas than a HR boiler, about 13% more gas. However, the HRe boiler generates electricity which an HR boiler does not. For every m3 gas the HRe boiler uses, it generates 13.14 kW electricity (Technische unie 2015).

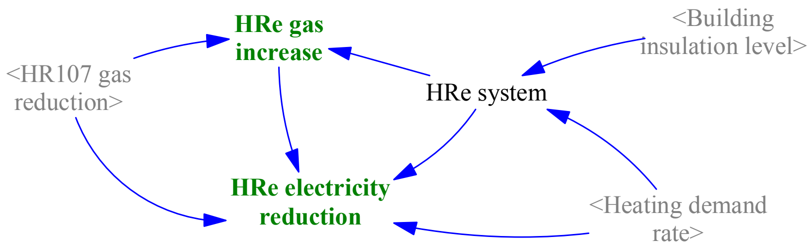

FIGURE 18 – SUB VARIABLE, MICRO COGENERATION, FOOTPRINT

4.3.5 On-site generation

When the generation on building site is not enough to make the building energy neutral, the second step is generating energy on site. This can be done with four technologies existing of; 1) heating pumps, 2) solar panels, 3) biomass boiler and 4) a heat cold storage (thermal storage). Again, wind turbines are not modelled for on-site generation as well due to a poor cost/return ratio as explained in the previous subchapter.

The first technology that is discussed are heating pumps. There is a variety of heating pumps available. They can either be gas powered or electric powered, also the generation differs they can either generate trough and water-water system, air-water system, air-air system or soil-water system. Scholten (TNO), Jacobs (TNO), Goes (Liander), and Kamerbeek (Liander) (2014) did a research about the differences between a gas and electric pump. They bring forward that when in applications the emphasis is on cooling, from an energetic point of view an electric heat pump is in the advantage. If the emphasis is on heating, then the gas heat pump is from an energetic point of view in the advantage, this is also supported by Bakker, van der Garde, Jansen, Traversari and Wagener (2010) which also did a research regarding the differences of gas heating pumps and electric heating pumps. This information is the foundation of the sub system of the heating pumps, see figure 19.

For the cooling an electric pump is used and for heating a gas driven pump is used. For the cooling of the building the best fit is an air-air system. This system has the lowest investment costs, but because the outside air is used it is not the best system for heating because when the demand for heat is the higher, the outside temperature decreases (Scholten, Jacobs, Goes and Kamerbeek, 2014). But due to the fact that the system is used for cooling and not heating, this is not a problem. For the gas driven heating system, an air-water system is the best fit. The efficiency of the electric pump and the gas pump are expressed differently. For the electric pump, the efficiency is expresses as a COP (Coefficient of Performance) value of 3, minus the 0.7 SPF (seasonal performance factor), as discussed earlier at the dew point cooling system. For a gas pump a different method is used and is expressed as GUE (Gas Utilization Efficiency) of 4.1 (Scholten, Jacobs, Goes and Kamerbeek, 2014). However, to keep calculating with the same values one the two has to be converted. Since there is already calculated with a COP in the previous technologies, the heating pumps will also be expressed with a COP value. GUE can be expresses as 0.41 times the COP value, this means that the COP value of the gas pump is 3.4 and again minus 0.7 SPF (Levy, 2012, p. 651).

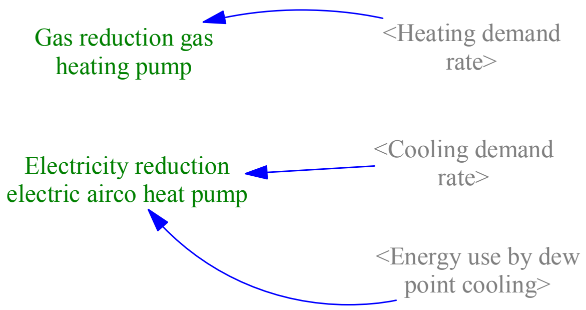

FIGURE 19 – SUB VARIABLE, HEATING PUMPS

At this point in the model the model needs to make a decision whether or not the system should be used. In the case for heating (also explained in appendix 11), first the focus is on energy reduction which is done by the use of a boiler system within the building itself (e.g. HR107 boiler, HRe system or a bio boiler), second the reduction by using on-site energy reduction technologies such as heating pumps and heat cold storage. As a last option (further discussed later in this paragraph), the generation of renewable energy is used by using either a biogas installation including cogeneration or without cogeneration.

The second technology (step 3.2) are solar panels (see figure 20), is already partly explained in the previous sub chapter. However, in this case the solar panels are positioned on the building site and not on the roof of the building. In this situation, only the calculations of a flat surface are needed with an optimal angle for solar panels on-site. Due to site situations it is sometimes not possible to orientate the panels in a south position (due to shadow of building, threes etcetera), in that case the panels can be placed in an east/west orientation. Also in this case it is sometimes not possible to install solar panels on the site due to trees or other reasons, in that case this sub system will be zero.

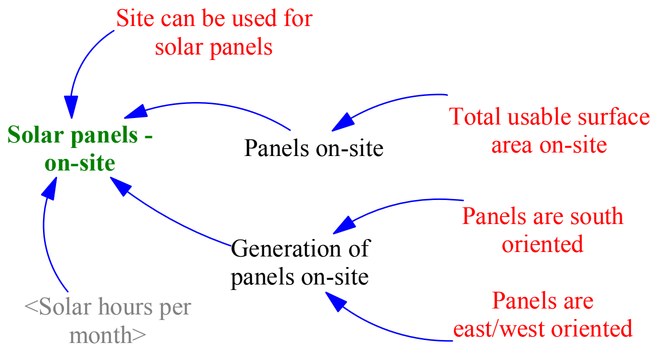

FIGURE 20 – SUB VARIABLE, SOLAR PANELS

The third technique regarding on-site generation is the use of a biomass boiler. A biomass boiler burns unlike gas or oil-fired boilers biomass, such as pellets or wood chips. These fuels are stored in a storage tank and transported to the burner. The combustion takes place by the supply of air. Through combustion of the biomass hot gases are produced in the boiler, which provide for the heating of water and spaces. Flue gases are discharged through a chimney. The use of a bio boiler ensures that the total heating of the building can be converted from a gas use base to a bio based system. The combustion value of wood chips is 10 GJ/ton and the boiler efficiency is the same as a CV boiler, 90% (Lobregt and van der Stoel, 2009). The sub variable in figure 21, shows the effect of converting a boiler into a biomass boiler, if there is chosen for a biogas boiler than the gas production of heating will be zero, but the generation of biomass trough wood chips is a ton per 10 GJ of previous used gas, in this case there is chosen to calculate with gas per m^3 instead of GJ, this means that a ton wood chips per 363.1 m^3 gas is needed.

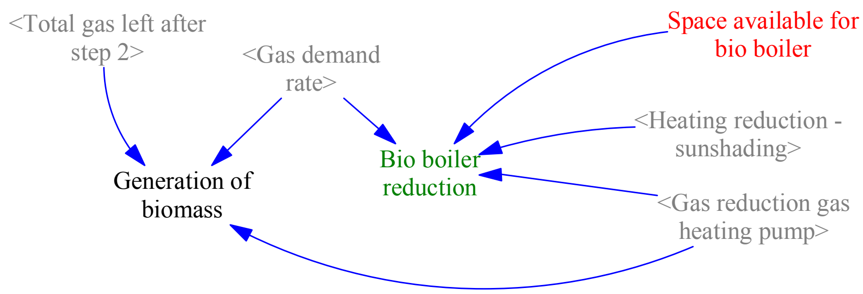

FIGURE 21 – SUB VARIABLE, BIOGAS BOILER

The last technique regarding off-site generation is the heat-cold storage (Dutch: warmte koud opslag). Heat cold storage e.g. thermal storage is a method to store energy in the soil in the form as heat or cold. The technique is used to heat buildings and or cooling. To determine if a location is suitable for heat cold storage, many variables are needed. The Dutch government has made a tool to determine what the possibilities are per location for a heat-cold storage system (www.wkotool.nl). Due to the many variables, this tool is used to determine whether or not the area can be used for a heat cold storage (variable: 'ground suitable for a heat cold storage'). The decision between an open or closed system is based on the size of the building, if the building is larger than 1.000 m^2 than an open system is advised, if the building is smaller than 1.000 m^2, then a closed system is preferred. A good working heat cold storage system ensures that 80% of the cooling is reduced and 50% of the heating. The sub-system can be seen in figure 22.

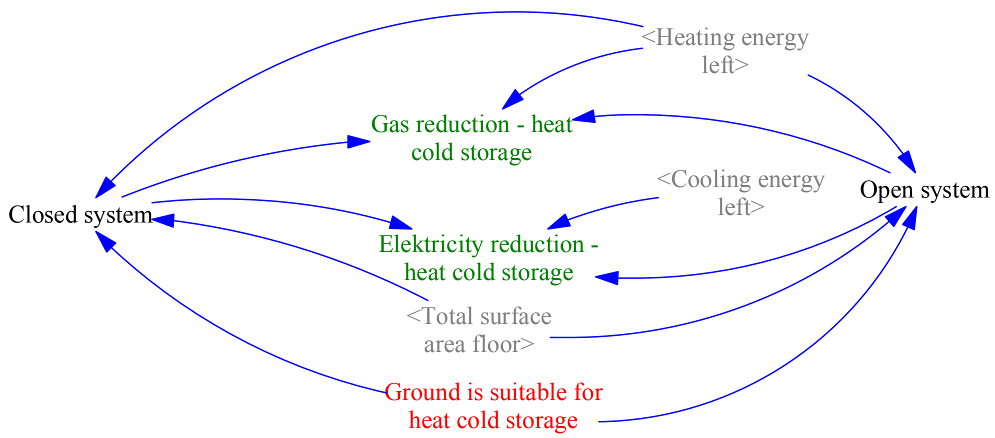

FIGURE 22 – SUB VARIABLE, HEAT COLD STORAGE

4.3.6 Off-site generation

If all the previous steps are completed and the building is not yet neutral, then the last step can be applied which is off-site generation. In the case of off-site generation, the generation of energy is not done on the building site itself. This generation can be done in three ways, 1) biogas installation, 2) wind turbine and as last 3) solar panels. The aim of off-site generation is that it is used on a small scale to connect buildings together and generate energy for a combination of buildings (depending on the scale). The difference with off-site supply is that off-site supply comes from energy through energy companies which generate renewable energy everywhere in the Netherlands.

The first technique is a biogas installation. Biogas is generated from wet organic material: organic residues from agriculture, residues from the food industry or residues from waste and water treatment. The Biomass is collected in an airtight silo where the mass is stirred and fermented by bacteria. The fermentation process produces the usable biogas. Biogas can be used in different ways, the most common way is using biogas in combination with a cogeneration system or using the biogas and transform it as natural gas. Biogas in combination with cogeneration gives electricity (yield is ca. 35%) and heat (yield ca. 60%) (Agentschap NL, 2010). Due to the fact that at this step in the model the generation comes from off-site supplies, the biogas installation is not only for the case study itself. The amount of buildings that can use the biogas installation depends on the energy use per building and the size of the biogas installation.

In this case there is chosen for a small biogas installation that can be used for 85 households or a combination with utility buildings. The efficiency of the biogas depends on the product that is used, for example manure provides a different amount of biogas then corn (1 m^3 manure provides 25 m^3 biogas, 1 ton corn provides 180 m^3 corn). In this case a real time example is used as foundation of the subsystem. The University of Wageningen used in their project 'van Hall Larenstein' 2400 m^3 ton manure and 500 m^3 ton corn. Together 150.000 m^3 biogas was produced. This means in terms of yield / savings that for a small installation with an integrated cogeneration system a production of 300 MWh electricity can be reached and 900 MWh heating (VHL, 2015). The source Energy consultant (2015) is used to convert the MWh into kWh and m^3 gas. Together, this gives the needed information for the model as can be seen in figure 23. If after the previous steps the electricity use of the building is not yet zero, this system will be used instead of a general biogas installation which only produces natural gas.

If it is chosen to work the biogas to natural gas, then it must be reconsidered that biogas has a lower methane concentration compared with natural gas. This means that biogas has 26% less methane (combustible component of natural gas) which means that making the total production amounted to over 111.000 m^3 of natural gas (VHL, 2015).

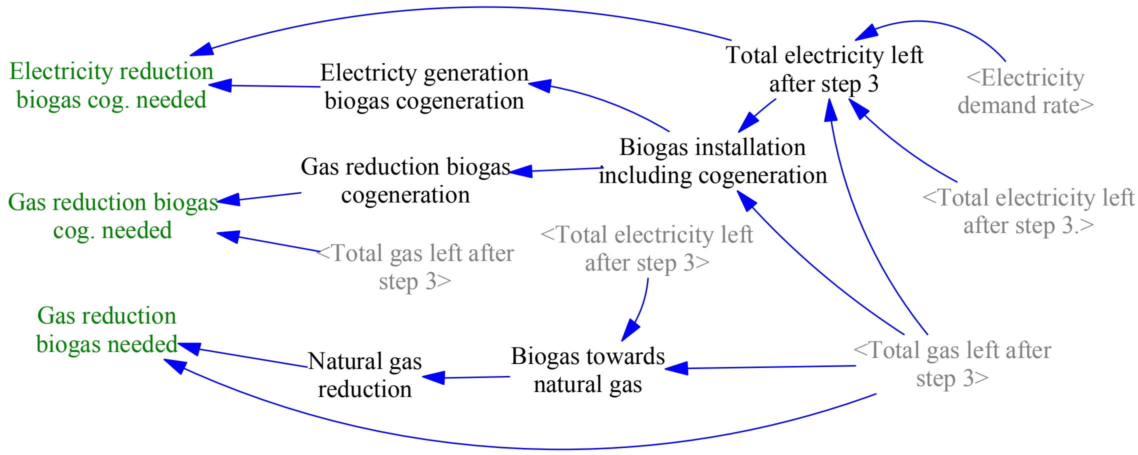

FIGURE 23 – SUB VARIABLE, BIOGAS INSTALLATION

The last technique in off-site energy generation is the use of a wind turbine (see figure 24). A wind turbine of 1 MV is a large investment of €1.500.000, but since the location of this windmill can be placed at an ideal location, the pay-back time is short. And the benefit of off-site generation, is that it can be done with more building owners than just one. To determine what the average wind speed is, the climate data of the KNMI is again consulted for the wind speed (KNMI, 2014). To determine the wind speed an average value of 2200 full-load hours a year are used in the literature in order to determine the generation of a windmill over a year. The exact full-load hours per month can be determined from the information provided by the KNMI. Table 20 shows the full-load hours per month average, which is used in the model as a look-up. At a speed of 14 m/s the windmill works for 100%, from a wind speed of 4 m/s the windmill will start producing energy, but only for 10% of its capacity.

TABLE 20 – FULL-LOAD HOURS WINDMILL PER MONTH

Month	Full-load hours
January	330
February	335
March	147
April	115
May	221
June	81
July	106
August	106
September	68
October	227
November	173
December	287
Total full-load hours	2196

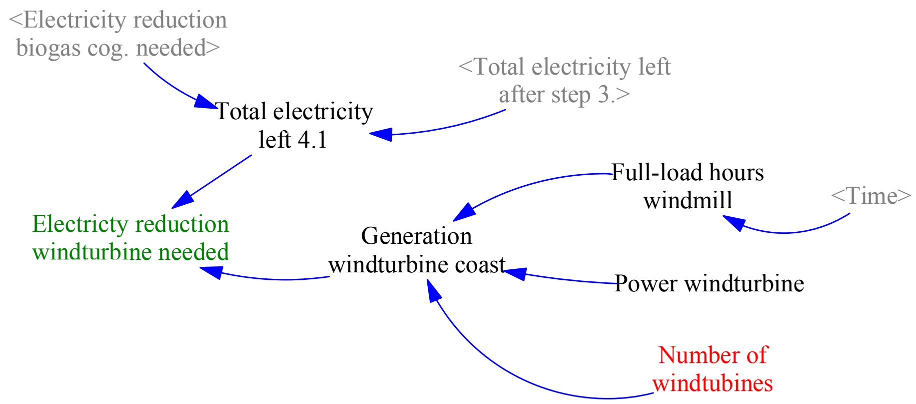

FIGURE 24 – SUB VARIABLE, WINDMILL

The last technology of off-site generation is the generation of solar energy by using solar panels, see figure 25. The same approach is used as in the building footprint generation and on-site generation. The difference with this sub-system is the amount of usable space that is available off-site. This depends on the buildings that are connected and which areas can be used for the generation of solar energy.

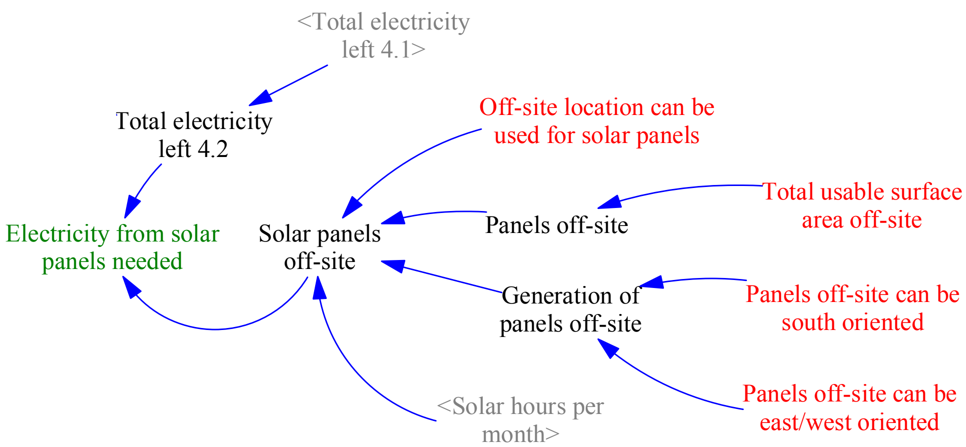

FIGURE 25 – SUB VARIABLE, SOLAR PANELS

The three off-site generation systems that have been discussed are connected. If after the previous steps the building is not yet neutral than there are several options of off-site generation. If there is only an electricity demand left after step 3 then the windmill and solar energy is the best off-site generation. If there is only gas left, than the best option is a gas based biogas installation. If there is both electricity and gas left, then the first step is applying a biomass installation with the combination of cogeneration, further explained in appendix 11.

4.3.7 Off-site supply

The last step in the model, is the use of off-site supply. If after the previous steps the building is still not energy neutral the use of off-site energy can be used. As explained in the previous chapter (chapter 3), this can be done by using energy companies which supply renewable electricity and gas. This approach is displayed in figure 26.

FIGURE 26 – SUB VARIABLE, OFF-SITE SUPPLY ELECTRICITY AND GAS

4.3.8 Tool design

In the previous subchapter the model was discussed. To make it user friendly for other people, a user interface is created with an output window. This means that the core structure of the model consists of three parts: the user interface (input), the simulation model and the output windows. This is displayed in figure 27. As can be seen, the user interface is the basis of the model which directs the calculation model and influences the model output.

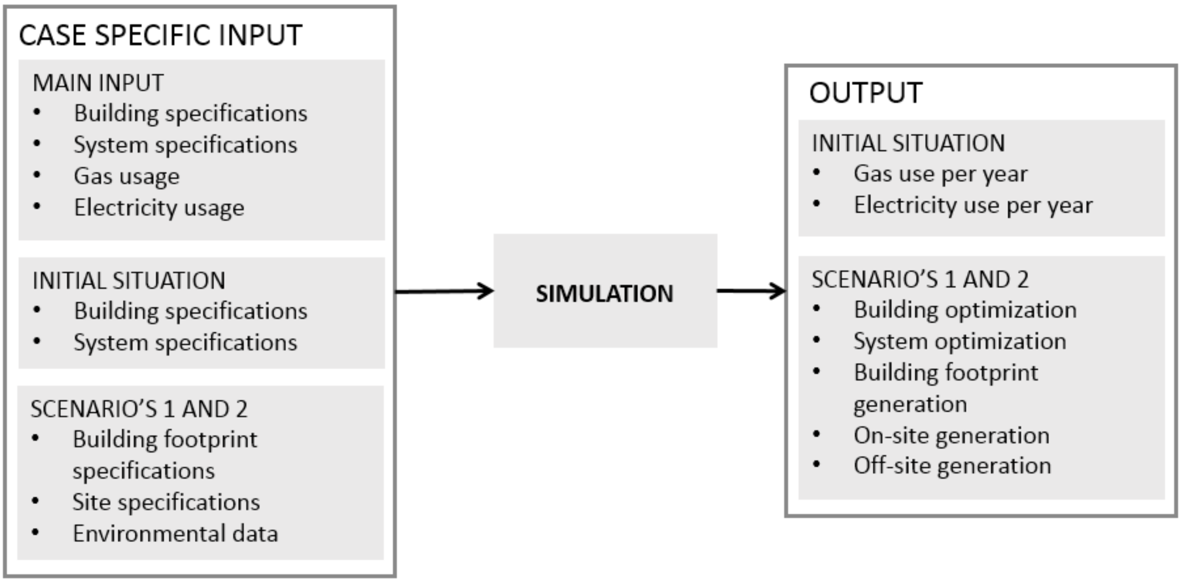

FIGURE 27 – INPUT AND OUTPUT MODEL

The first part, the user interface exists as a guide for using the model. The user interface (UI) explains the user what steps to take and what simulation outcome is visualized. By using a UI, the user doesn't need to handle the calculations within the model itself. The formulas behind the variables is in many cases complex and the understanding of the formulas is not relevant for the interpretation of the outcomes of the simulation. Previous, the model is explained and the exact steps behind it. If people wants to understand the formulas, they can be found in appendix 10. The UI corresponds with the red variables displayed in appendix 9. The UI of the red variables can be found in appendix 14 and appendix 15. As can be seen in the appendix, the user is guided through seven steps. The first 5 steps exist of inserting the information into the model (e.g. step 1 building optimization information; step 2 system optimization information; step 3 building footprint information; step 4 generation on-site information; step 5 off-site generation information). Step 6 exist of adjusting the boundaries (if the time line needs to be adjust for 1 to 2 years for example) and run the model. The last step exist of interpret the output windows provided in the green variables in appendix 9. The generation of the data can be done through a questionnaire (see appendix 15).

For the generation of the data several steps can be taken. For the identification of the building and system specifications a walk through the building can be made where all the specifications can be noted. Also, building plans and other information sources can be consulted for answering the questions in the questionnaire. The identification of the gas demand and electricity demand is more complex. It is possible that not all the information needed for the identification of the electricity demand and gas demand is available, in that situation several things can be done.

Firstly, an assumption of the energy use of the building can be made. There is a lot of data available per building type what the energy use is per square meters. If there is a need of a quick results, than the assumption regarding the energy use can be used, in that case the electricity demand and gas demand can be stated as shown in table 21. However, it is an assumption which means a less specific advice can be given. The ratios described in table 21 may vary widely, for example by differences in building year, operating times or due to the already implemented measures. Each type has three values to indicate the bottom 20% and the upper 20% of the observations. The median (50%) is also shown, because there may be a skewed distribution in the observations, which means that it can be the case that the median is not located exactly in the middle between 20% and 80%. Chapter 4.6 describes how accurate these values are trough a validation.

TABLE 21 – ENERGY ASSUMPTION OFFICE BUILDING

		Gas [$m^3/(m^2/year)$]			Electricity [$kWh/(m^2/year)$]		
Types		20%	50%	80%	20%	50%	80%
1	Office 200 – 500 m^2	6	21	37	35	109	182
2	Office 500 – 10.000 m^2	6	13	32	32	85	138
3	Office > 10.000 m^2	6	10	28	28	79	95

SOURCE: SENTERNOVEM (2007)

Secondly a more detailed approach can be used by monitoring the building for a year and then fill in the data gathered from that monitoring. In that case the information will be very specific and a more detailed, as can be seen in chapter 4.6.

4.4 CASE STUDY

This part of the research focuses on applying the knowledge gained from the previous chapters (e.g. literature research and expert interviews) and testing the model on a case study. The case study is the head office building of Heijmans (RM1) in Rosmalen, see figure 28. The building of Heijmans is a good example for testing the model, due to the feature that is an office building, but also that there is a lot of information available of the building and a report is available (energie prestatie advise, 2008) for the validation. The information of the building is gathered from K. Dorst (2015) and the available information from Heijmans (2015). The building is not in possession of Heijmans, but Heijmans rents the building. Next, the building is discussed with main topics such as on the climate installation, the construction of the building, material use, and electronica use. All this information is needed for the model discussed in chapter 4.3 to fill in the questionnaire in appendix 16.

FIGURE 28 – HEIJMANS ROSMALEN 1 **SOURCE: HEIJMANS (2015)**

4.4.1 Description case study

Climate installation – One or more climate installations have the task to keep a building comfortable while the employees are working within the building. The head office of Heijmans uses five different kind of systems to keep the building comfortable, see table 22. The first system – ventilation – is done through a mechanical balance system using lattices as the supply in the space. The mechanical balance system uses heat recovery with two heat exchangers. The second system – space heating – is done through a HR107 boiler and a VR gas boiler, the distribution is either done through water, air or a combination of the two. The capacity of the boilers is 349 kW for the HR107 boiler and 218 kW for the VR gas boiler. The pomp control uses a 50% automated speed control. For the cooling of the building a compression cooling system is used. The distribution of the cooling is done through water and air. The cooling system also uses a 50% automated speed control for the pomp control. The fourth installation – hot water generation – is done by using an electric boiler. The last system – humidification – uses an electric steam humidification system without moister recovery. Together this information can be used for the input data for the model.

TABLE 22 – CLIMATE INSTALLATIONS OF THE CASE STUDY

CLIMATE INSTALLATION	SYSTEM/GENERATION
1) Ventilation system	Mechanical balance system, including lattices and heat recovery
2) Space heating	HR107-gas boiler + VR- gas boiler with >50% automated speed control
3) Space cooling	Compression cooling with water and air distribution, >50% automated speed control
4) Hot water generation	Electric boiler, taps within 3 meters and one or more further than 3 meters
5) Humidification	Electric Steam humidification without moister recovery

Construction – As told in chapter 4.3.3 the insulation value of the building determines how much heating is lost. With a high insulation value there is less heating needed, however it can increase the cooling need. In table 23 the construction overview of the building can be seen. Not only the insulation values are needed, also the materials of the building envelope are needed to gain a clear view about the building situation, these values can be seen in table 24 and table 25 shows the dimensions, orientations and the boundary of the architectural structures.

TABLE 23 – CONSTRUCTION OF THE BUILDING

CONSTRUCTION	Rc [m^2K/W]	U [W/m^2K]	ZTA [%]
Outside wall	2.50		
Partition	2.50		
Floor (outside/ground)	3.00		
Roof	3.00		
Door	0.33		
Window type 1		1.4	35
Window type 2		2.9	20

TABLE 24 – MATERIAL USE BUILDING

CONSTRUCTION	MATERIAL		
Outside wall	Insulation thickness unknown	Building period > 1992	
Partition	Insulation thickness unknown	Building period > 1992	
Floor	11 cm insulation		
Roof	11 cm insulation		
Door	D02 insulated door		
Window type 1	Wood or plastics	HR++	Reflective coating
Window type 2	Wood or plastics	Double glazing	Reflective coating

TABLE 25 – DIMENSION, ORIENTATION AND BOUNDARY OF THE BUILDING

CONSTRUCTION	AREA [m^2]	ORIENTATION	BOUNDARY
Outside wall	3878.4	-	Outside air
Roof	1962	-	Outside air
Window type 1	654	South	Outside air
Window type 1	532	East	Outside air
Window type 1	510	West	Outside air
Window type 1	107	North	Outside air
Window type 2	388	North	Outside air
Floor	1962	-	Ground

Energy sectors – Each sector has its own user functions and is connected to a climate control system which has all kinds of architectural structures, equipment and lighting. The organization and the use of the building determines to a large extend the energy sue of the building. With a high staffing level, low user time and a high temperature settings the energy use will be high. The total surface are of the building is 10.252 m^2, with a maximum capacity of 1025 people. The building is used 50 weeks a year, 5 days per week from 06:00 till 22:00. The staffing level influences the energy use to a large extend, the average staffing level is overall 60%, however the staffing level has a large effect on the overall energy levels. To show the effect of the staffing level on the energy use, the occupancy rate over a year is varied between 30% and 90%. Besides the climate installation, there are other installations in the building which uses energy. Examples are computers, copy machines, telephones etcetera. Most devices use electricity, but sometimes gas or steam. In table 26, the office equipment of the case study is shown. And as last, the lighting of the building. The building uses 9.0 W/m^2 as lighting, including presence detection.

TABLE 26 – OFFICE EQUIPMENT

DEVICE	TYPE	YEARLY CONSUMPTION
Fan coil	Electric device	280 x 260 kWh
Copiers	Electric device	11 x 2.600 kWh
PC	Electric device	332 x 744 kWh
Screen	Electric device	324 x 80 kWh
Computers	Electric device	7 x 200 kWh
LCD televisions	Electric device	9 x 875 kWh
Beamers	Electric device	9 x 500 kWh
UPS server space	Electric device	1 x 26.280 kWh
Cooling server space	Electric device	1 x 8.760 kWh
Coffee machine	Electric device	15 x 1.500 kWh
Soda machine	Electric device	1 x 400 kWh
Revolving door	Electric device	4 x 100 kWh
Electric door	Electric device	4 x 100 kWh
Elevator	Electric device	22.5 x 7 kWh
Kitchen elevator	Electric device	10 x 10 kWh
Air curtain	Electric device	1 x 470 kWh
Lighting building	Electric device	1 x 175.000 kWh
Site lighting	Electric device	20 x 438 kWh
Extra lighting	Electric device	10 x 40 kWh
Parking lighting	Electric device	1 x 35.000 kWh
Various control room	Electric device	1 x 17.500 kWh
Extra split unit	Electric device	1 x 6.000 kWh
Various equipment	Electric device	1 x 16.000 kWh
Kitchen equipment	Electric device	128.506 kWh
Aberrant use	Electric device	1 x 30.000 kWh
Air curtain	Gas device	1 x 3.200 m^3
Total electricity use	834.736,5 kWh	
Total gas use	3.200 m^3	

Energy use – Now, the energy use of the building in the present situation is discussed. All the information regarding the situation of the building envelope, systems and office equipment are known, together they cause for a total energy use of average 1.109.000 kWh and 97.000 m^3 gas use (based on data gathered from monitoring). In table 27 the energy use per section in the current situation is shown. Figure 29 gives a figurative display of the total elasticity and gas use.

TABLE 27 – ENERGY USE PER SECTION IN CURRENT SITUATION

SECTION	TOTAL	PER M^2 FLOOR	UNIT
Heating	97.000	9.5	m^3 / year
Cooling	33.270	3.3	kWh / year
DHW	22.180	2.2	kWh / year
Moistening	66.540	6.5	kWh / year
Lighting	199.620	19.5	kWh / year
Office equipment	654.310	63.8	kWh / year
Ventilation	110.900	10.8	kWh / year
Pumps	22.180	2.2	kWh / year
PV panels	0	0	kWh / year
CHP	0	0	m3 / year

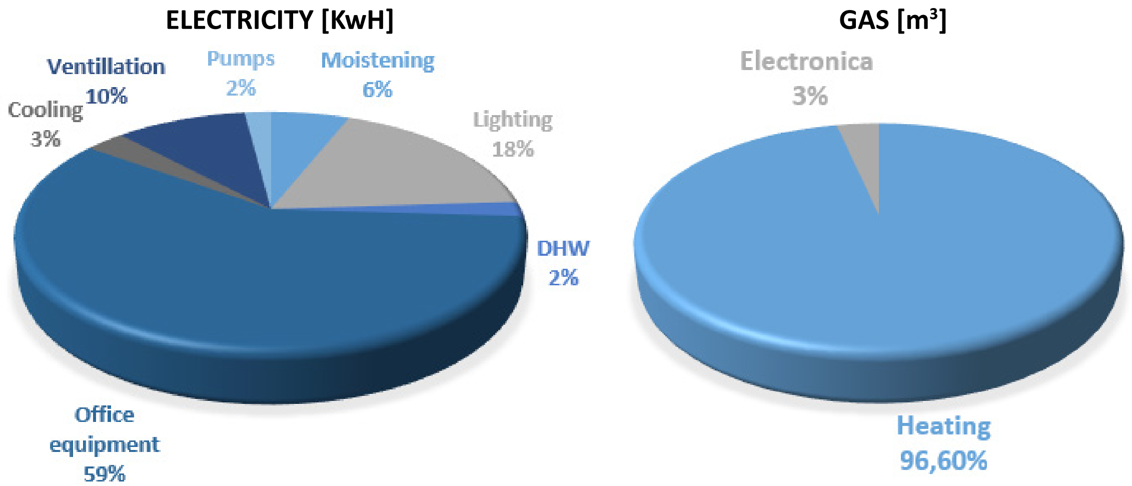

FIGURE 29 – OVERVIEW ENERGY USE PER SECTOR

4.4.2 Input data model

After the discussion of the case study, the data described in chapter 4.4.1 can be inserted into the questionnaire (see appendix 16) and filled into the model by using the user interface (see appendix 14). As already told, the foundation of the information is Heijmans (2015), the document energie prestatie advies (2008) and from K. Dorst (2015). No assumptions have to be made for this case study, however the assumptions are tested in chapter 4.6.1 to see if they provide the same data as with actual data. The results of the case study are discussed in the next paragraph.

4.5 RESULTS

4.5.1 Simulation

After the information from the questionnaire (see appendix 16) is filled into the user interface, the results can be generated. For the case study the data is inserted and a simulation can be executed for optimization. The results of each step (phase) in reaching energy neutrality is discussed and shown if energy neutrality is reached yes or no.

Initial situation – for the initial situation the data of the gas use and electricity use of the case study was needed. The data that is used is from monitoring in the year 2014. Figure 30 and 31 show the gas and electricity demand of the case study. The total energy demand is fully relying on fossil fuels, at this moment the case study doesn't use any renewable energy generation. As can be seen in figure 30, the total use of gas in 2014 was average 97.000 m^3 gas spread out over the year. Figure 30 shows the average gas demand (y-axis) of the building per month over a year time (on the x-axis is 0 January and 11 is December), in this situation the gas demand in January (time is zero) is approximately 17.000 m3 gas. Figure 31 shows the average electricity demand of the building per month (again from 0 is January and 11 is December) where in January (time is zero) the average electricity demand 155.000 kWh is. When all the months are summed up a total of average 1.109.000 kWh is used during a year.

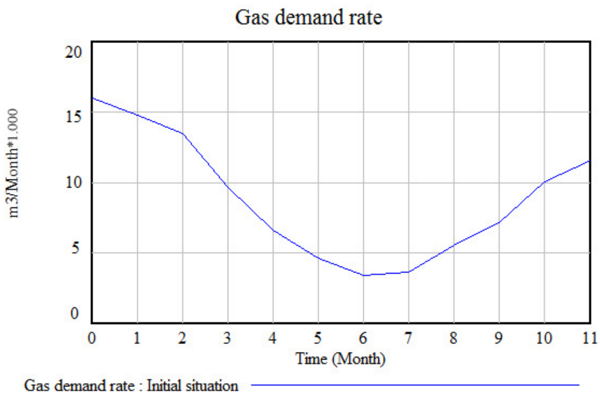

FIGURE 30 – GAS DEMAND CASE STUDY

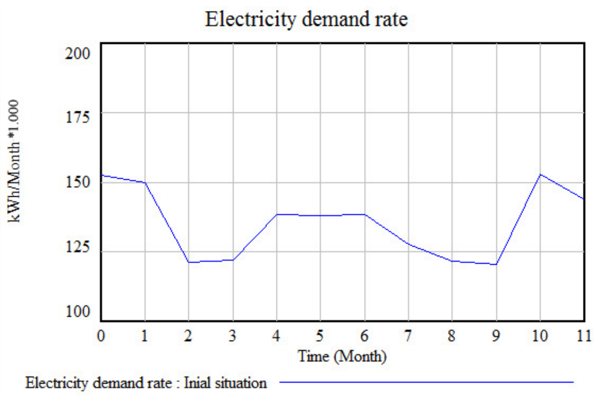

FIGURE 31 – ELECTRICITY DEMAND CASE STUDY

Building optimization – the first step in optimizing the building exists of cavity wall insulation, roof insulation, floor insulation and window insulation. Cavity wall insulation is not possible because of moistening ventilation. Also roof insulation is not a possibility because of the construction. Floor insulation is not possible because of the garage below the building. One aspect of the building optimization does have a result, which is HR+ insulation. Only a small part of the building still has double glazing, however as can be seen in the results, the effect of changing the double glazing into HR+ glazing is very small (40 m^3 gas reduction of a total of 97.000 m3 gas). This means that it is not preferable to change the glazing into HR+. In conclusion, in step 1.1 only the windows can be optimized with an effect of 40 m^3 gas reduction which causes a 0.04 % gas reduction. Energy neutrality has not been reached in this step.

System optimization – for system optimization there were five possibilities in optimization. Four out of five optimizations are executed. First regarding the ventilation system, at this moment there is no demand controlled ventilation system present. By implementing this system the electricity use will lower with a total of 45.500 kWh over a year. The second technology is using a dew point cooling system, implementing this system has a significant effect on the overall cooling demand. Dew point cooling will lower the energy demand with 31.500 kWh over a year. Also by changing the lighting into low-energy use LED-lighting ensures that the electricity use will be lowered with 134.600 kWh over a year. The last reduction regarding system optimization is the use of sun shading. The cooling and heating demand will change due to the sun shading. The sun shading will decrease the need for cooling with 10.400 kWh but the heating will go up with 5.000 m^3 gas. In conclusion after step 1.2 the total electricity reduction is 222.000 kWh and the total gas increase is 5.000 m^3 gas. Neutrality has not been reached.

Generation on building footprint – after the building optimization and system optimization, there is still a gas and an electricity stream left. The second step is looking at generating renewable energy within the building footprint. There are two options for generating renewable energy on the building footprint, by using solar panels or installing a mini cogeneration system (HRe system). Both technologies have a result of zero, which means that they are not used. Solar panels are zero in this system, because calculations Heijmans show that solar panels on the roof have a pay-back time of more than 20 years and are not used in this case study. Also the HRe system is zero, the total gas use is above 2.000 m3, but the insulation level of the building is at the start of this process is high, which means a better system or technology should be chosen for generating electricity and gas. In conclusion, step 2 has no effect on the lowering of the energy demand which means neutrality has not been reached.

Energy generation on-site – as can be seen in the previous step, the building is not yet energy neutral, not in the gas use as in the electricity use. The next step is generating renewable energy on the building site. In the model there are three technologies for generating energy. Two out of three technologies are used in this model which include the gas heating pump and the biomass boiler. The total energy generation out the soil is 22.000 m^3 gas. The total generation of the biomass boiler is 77.800 m^3 gas. The solar panels on site are zero in this system, due to the fact that the site has too many obstacles such as trees, which means that the solar panels are not profitable for this specific location. In conclusion, the energy reduction from step 3 is 99.800 m^3 gas. This means that the gas demand has reached 0 m^3 fossil gas and is neutral, however the electricity demand is not.

Energy generation off-site – as can be seen in the previous step, the gas demand of the building is compensated with renewable energy, but the electricity is not. Which means that the building is not yet energy neutral, but only the fossil electricity of the building has to be lowered. The last step – generation of renewable energy off-site – can be used to lower the electricity to zero. As told in the explanation of the model, at this point in the system the model know what energy demand is left and chooses what the best fit is in relation with the other technologies. In this situation there is a wind turbine needed including solar panels off-site. Figure 32 shows the energy generation form a wind turbine (y-axis), during a year (on the x-axis from 0 which is January till 11 which is December), as can be seen the generation form wind varies during a year, in the winter months (9= October till 2 = February) the electricity generation is the highest, for example the electricity production in January is 340.000 kWh. Figure 32 shows that the wind turbine can compensate for the most of the electricity, namely 980.000 kWh. The remaining electricity can be generated from solar energy off-site which generates the remaining 6.500 kWh.

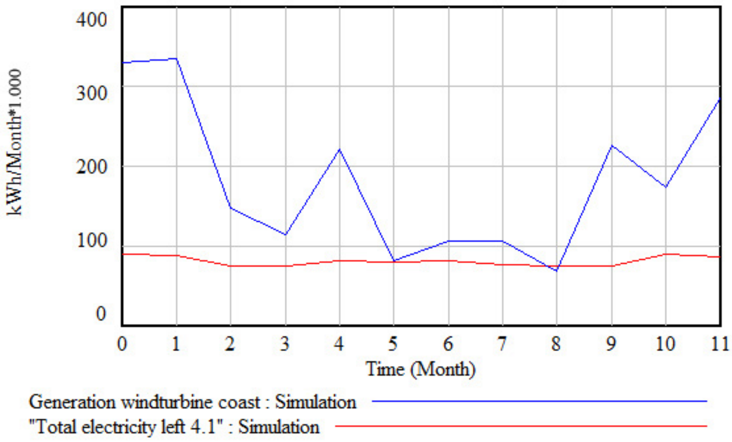

FIGURE 32 – ELECTRICITY STREAM AFTER STEP 3 VERSUS ELECTRICITY GENERATION OF WIND TURBINE

Off-site supply – as can be seen both the electricity and gas demand are zero, this means that there is no off-site supply needed and the building is energy neutral after step 4. After these steps can be concluded that the building of Heijmans can be made energy neutral.

The steps above are summarized in table 28 and 29. Table 28 describes all the above steps specific for the electricity reduction, electricity neutrality is reached after step 4. Table 29 describes all the above steps specific for the gas reduction, all the steps show a reduction except step 1.2 system optimization. This is due to the fact that if sun shading is applied, the heating demand increase, because natural heating of the building by solar lighting is kept away. Gas neutrality is reached after step 3. Overall, energy neutrality is reached after step 4.

TABLE 28 – OVERVIEW PACKAGE LIST OF SIMULATION (ELECTRICITY REDUCTION)

PHASE	TECHNOLOGY IMPROVEMENTS	ELECTRICITY REDUCTION [kWh]	REDUCTION PER STEP [%]	TOTAL REDUCTION [%]
1.1 Building optimization	-	0	0.00	0.00
1.2 System optimization	Demand controlled ventilation	45.500	3.76	3.76
	Dew point cooling system	31.500	2.61	6.37
	Change lighting system	134.600	11.14	17.51
	Installing sun shading	10.400	0.86	18.37
02 Generation on building footprint	-	0	0.00	18.37
03 Energy generation on-site	-	0	0.00	18.37
04 Energy generation off-site	Windmill	980.000	81.09	99.46
	Solar panels	6.500	0.54	100.00
05 Off-site supply	-	0	0.00	100.00

SOURCE: APPENDIX 17

TABLE 29 – OVERVIEW PACKAGE LIST OF SIMULATION (GAS REDUCTION)

PHASE	TECHNOLOGY IMPROVEMENTS	GAS REDUCTION [m^3]	REDUCTION PER STEP [%]	TOTAL REDUCTION [%]
1.1 Building optimization	Change double glazing window into HR+ glazing	40	0.04	0.04
1.2 System optimization	Installing sun shading	+ 5.000	-5.14	-5.10
02 Generation on building footprint	-	0	0.00	-5.10
03 Energy generation on-site	Gas heating pump Biomass boiler	22.000 80.230	22.62 82.48	17.52 100.00
04 Energy generation off-site	-	0	0.00	100.00
05 Off-site supply	-	0	0.00	100.00

SOURCE: APPENDIX 17

Figure 33 and 34 give a figural display form the in table 28 and 29 described results. Figure 33 shows the results of the reduction of the electricity demand per step and figure 34 shows the reduction of the gas demand per step. As can be seen in figure 33, the initial situation is an electricity demand of 1500*1.000 kWh over a year. By applying the steps in table 28, the fossil electricity use can be reduced to zero. Zero fossil electricity is reached after step 4. Figure 34 shows the same effect for the gas demand, the initial situation of the building is about 94*1.000 m^3 fossil gas demand over a year. By applying the steps described in table 29, zero fossil gas use can be reached. Again, step 1.2 (system optimization) causes a gas increase due to the fact that sun shading increases the heating demand (less heating from solar lighting) and reduces the cooling demand.

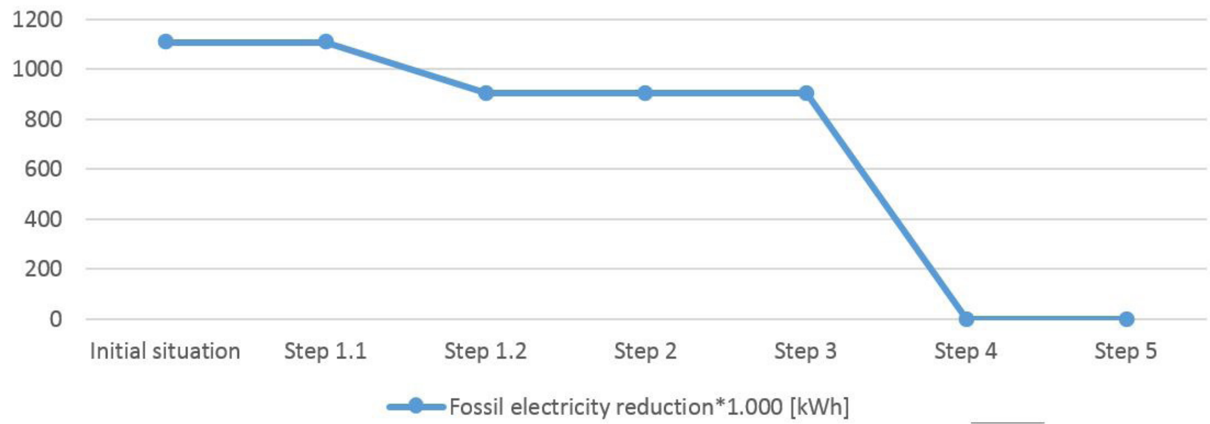

FIGURE 33 – ELECTRICITY REDUCTION PER STEP BASED ON TABLE 28

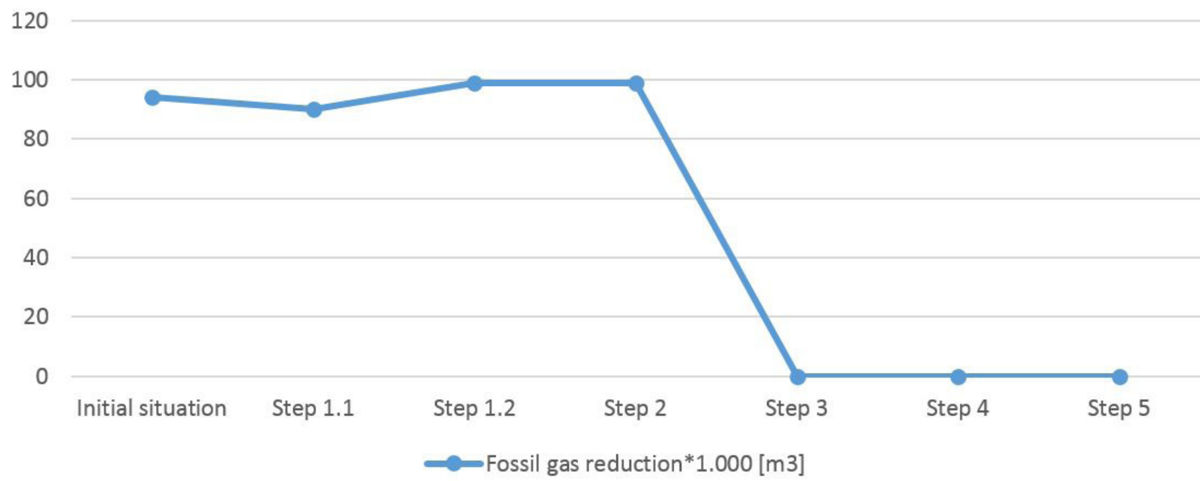

FIGURE 34 – GAS REDUCTION PER STEP BASED ON TABLE 29

Explanation of the graphic results from the model

Figure 35 and 36 show the effect each step has on either the electricity demand or the gas demand per month. Figure 35 shows the gas demand of the building over a year (on the x-axis is 0 January and is 11 December) the total gas demand (explained in m^3 gas per month on the y-axis) varies during a year, for example the gas demand of the building in the initial situation (blue line) in January is approximately 16.000 m^3 gas. As can be seen in figure 35, step 3 (the black line) has the most effect on the overall gas reduction per month over a year, this line is situated above the average gas demand (blue line). Step 1.2 (green line) gives a gas increase instead of a decrease, because the value of step 1.2 is below zero, which means more gas is needed instead of a reduction. Step 1.1 (red line) has also a (minimum) effect on the gas reduction. The other steps (step 2 – gray line, step 4 (dark red line) and step 5 – light blue line) are 0, which corresponds with the data provided in table 29.

Figure 36 shows the effect of each step on the electricity demand of the building. Again, the blue line is the initial situation the electricity demand of the building. The figure shows per month (on the x-axis is 0 January and 11 is December) what the electricity use is (on the y-axis the electricity use per month), for example in the initial situation (blue line) the electricity use of the building in January is 120.000 kWh. Step 4 (black line) has the most impact on the average electricity reduction. Besides step 4, provides step 1.2 also for a significant electricity reduction. Step 1.1 is not shown in this graph, because step 1.1 has no effect on the electricity demand of the building. Step 2 (red), step 3 (green) and step 5 (dark red) are all zero, which corresponds with the data provided in table 28.

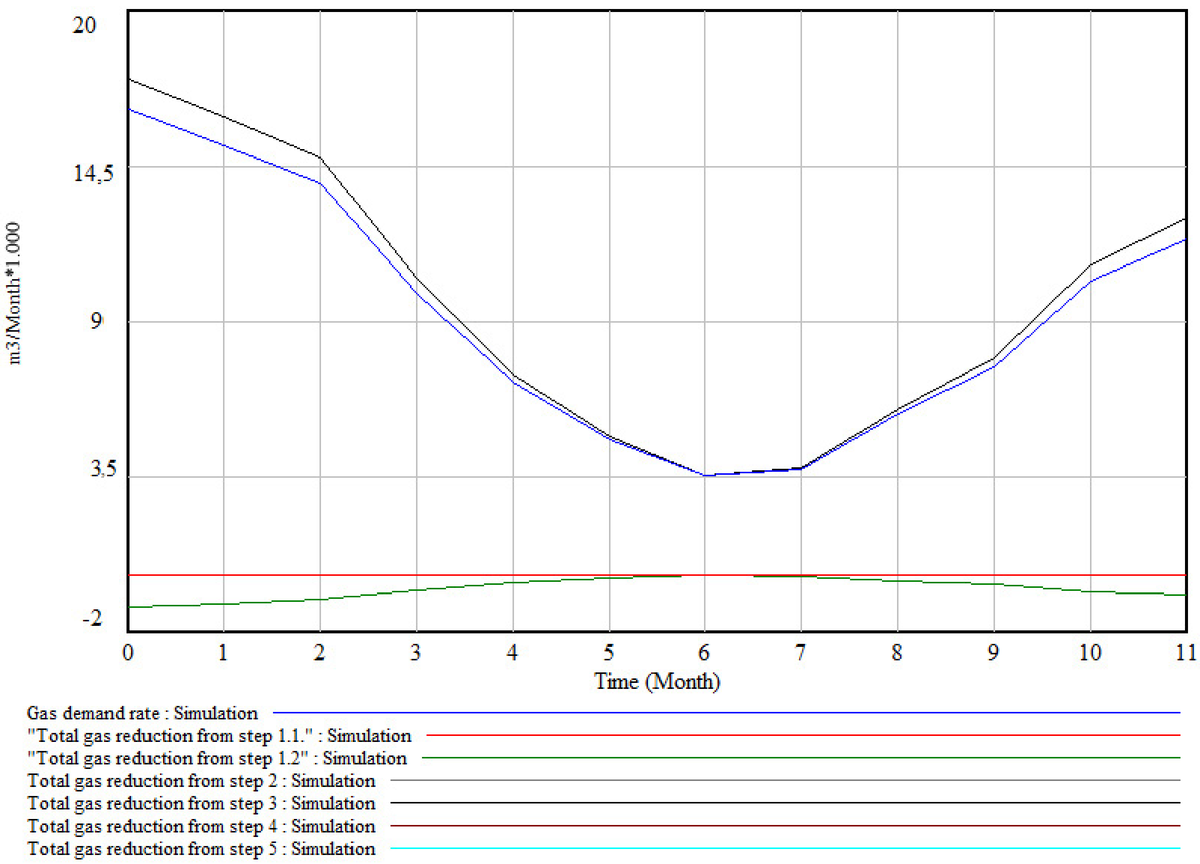

FIGURE 35 – EFFECT OF EACH STEP ON THE GAS DEMAND

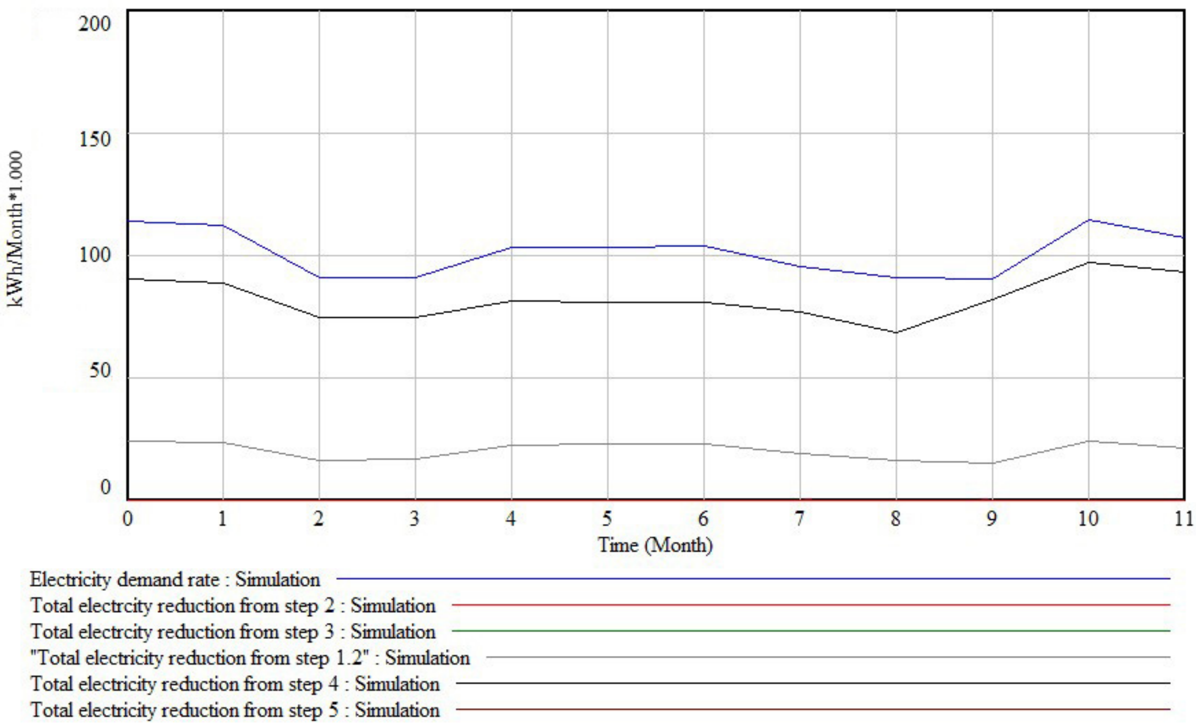

FIGURE 36 – EFFECT OF EACH STEP ON THE ELECTRICITY DEMAND

After the effect per step is discussed, the total effect per step per month is discussed and displayed in figure 37 and 38, the graphs can be read in the same way as previous discussed. Figure 37 shows how high the initial gas demand is after each step. As can be seen, this means that after step 1.1 the gas demand is almost the same as in the initial situation. Step 1.2 has also an effect on the gas demand, but is causes an increase instead of a decrease of the gas demand. Step 2 is a gray line, and cannot be seen in figure 37, however as can be seen in figure 33, that step was 0 and is the reason for not seeing that line in the graph. Step 3 (black line) ensures that the fossil gas demand decreases to 0, the line is horizontal on the 0 m3/month axis.

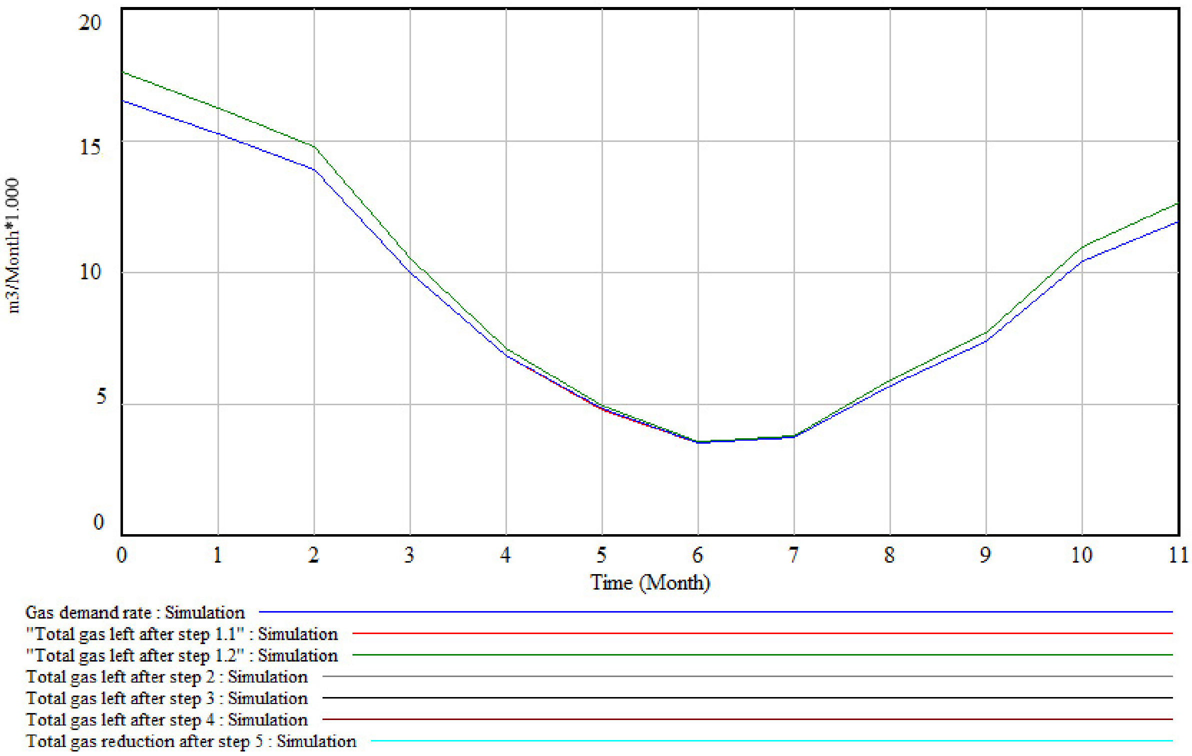

FIGURE 37 – TOTAL EFFECT OF THE STEPS ON THE GAS DEMAND

For the electricity demand in figure 38, can be seen that the initial situation is again the blue line. As discussed step 1.1 is not shown in the graph because there is no electricity reduction in that step. Step 1.2 (red line) has a significant effect on the overall electricity reduction and lowers with an average of 25.000 kWh per month. Again step 2 has no effect on the electricity reduction and cannot be seen in this graph but can be seen in table 28, this also applied to step 3. Then, step 4 (black line) ensures that the overall electricity

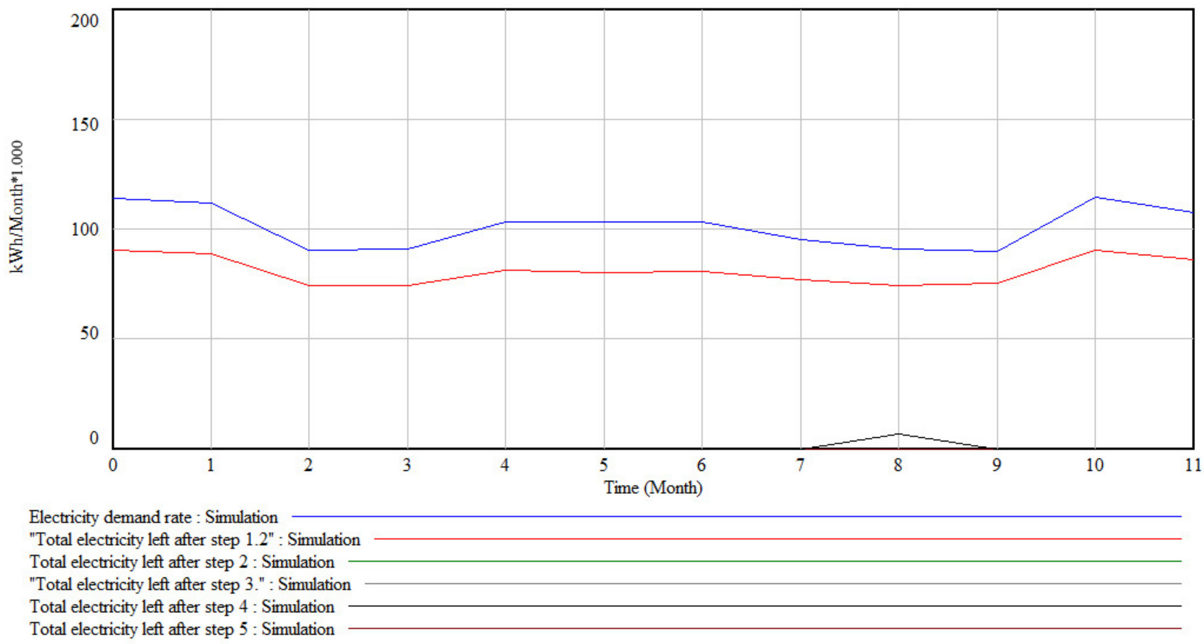

FIGURE 38 – TOTAL EFFECT OF THE STEPS ON THE ELECTRICITY DEMAND

4.6 VALIDATION

The validation of the model is important to show whether or not the model is effective and represents the reality. In many cases models are based largely on assumptions to enable simulating a system and future behaviour, which means that the outcome of a simulation can differ from what will happen in reality. If that is the case than the robustness and conclusions to uncertainty need to be tested with the help of a sensitivity analysis. However, in this situation no future behaviour is used which means that the validation of the model needs to be done by using a different approach than using a sensitivity analysis. As discussed in subchapter 4.2.1, the validation can also be done by using historic data and reference mode. In this case the validation is done by using the historic data divided into two approach 1) validation of initial data and 2) the validation of the measure package by using the report energy performance advice (2008). Also, the same expert(s) which are used previous, are used from determining whether or not the answers provided give a realistic view.

4.6.1 Historic data – validation initial data

The validation of the initial data is split up into two parts. The first part focuses on the accuracy of the values which are based on assumptions and to test if they represent the actual data. The second part focuses on the validation of the initial situation and how the energy demand is modelled over a year.

First starting with the first part of the validation where the accuracy of the assumed is tested. Chapter 4.3.8 describes the generation of the electricity demand data and gas demand data. As told, it could be difficult to generate the data. If it is not possible, than the assumptions of the energy per square meter could be used. In order to test if these values represent the reality, the values are compared with the actual data. As told in table 21 in chapter 4.3.8, the electricity and gas assumption can be based on the different office building types. In this situation, the total square meters of the building is 10252 m2, which means that the 3 type is used for the validation. Figure 39 and 40 show the validation of the gas and electricity demand.

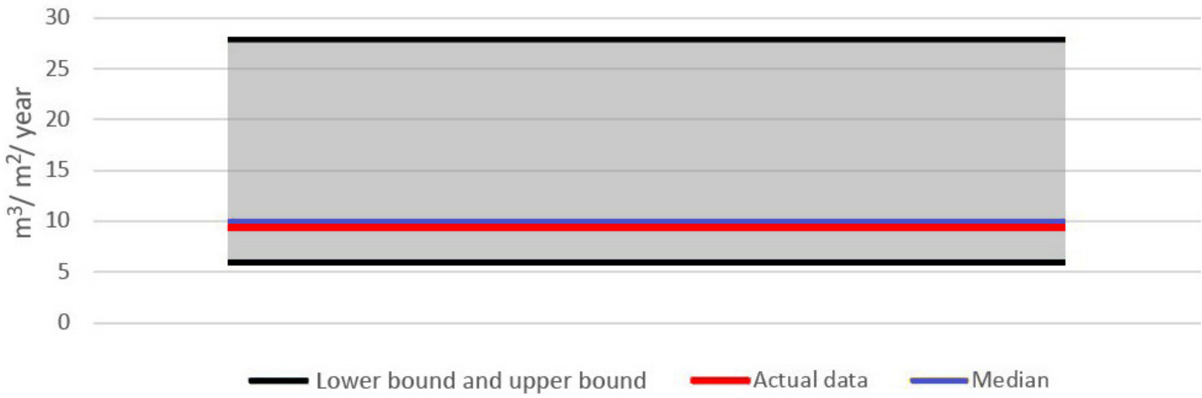

FIGURE 39 VALIDATION GAS DEMAND PER SQUARE METER PER YEAR

Figure 39 shows the lower and upper bound of the gas demand, based on table 21 in chapter 4.3.8. The blue line in the figure shows the median which will be used for testing the initial situation. As can be seen, the actual data and the assumed median vary little, which means that for this case study the assumption of 9 m^3 gas demand per square meter is a good assumption and representation of the reality.

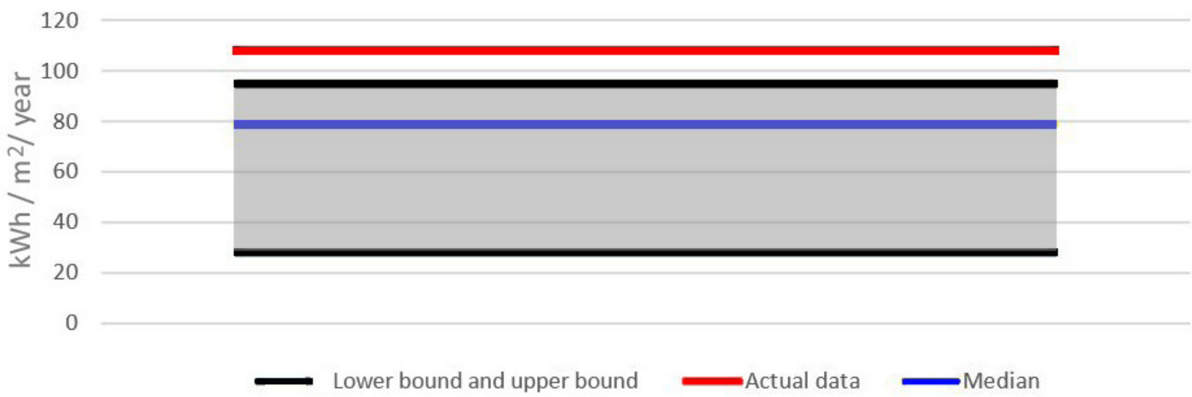

FIGURE 40 VALIDATION ELECTRICITY DEMAND PER SQUARE METER PER YEAR

Figure 40 shows the assumed electricity demand with the lower bound and upper bound. As can be seen, the actual data is above the upper bound and does not correspond with the assumption made in paragraph 4.3.8. Because each building is different, the electricity use can differ per building. In this situation the electricity demand is higher than the assumed data. The actual electricity demand per square meter is 37% higher than the average modelled electricity demand. The reason for this could be that the electronica use of the building is higher in 2014 than the average use, this also corresponds with the data gathered from monitoring. Each year a different amount of electricity is used for 2013 the monitoring was 570.000 kWh (which corresponds with an electricity use of 56 kWh per square meter), which is within the boundaries but is 30% lower than the average modelled electricity demand. In conclusion can be said that the electricity use can vary with peaks 30%-40% higher or 30%-40% lower than the average modelled electricity demand.

In the model, the electricity demand and gas demand is modelled with the use of demand curves to show what the average electricity and gas demand is per month over a year time (see also appendix 12). Also, the assumption data in chapter 4.3.8 is again used to see if the results are a representation of the real world. The validation of the initial situation is done by using the actual data gathered from monitoring. Table 30 shows an overview of the data gathered from the model and the actual data gathered from monitoring. The data used from monitoring is based on data over the year 2014. Figure 30 in chapter 4.5.1 showed the modelled average gas demand over a year and figure 31 in chapter 4.5.1 showed the average modelled electricity use per month over a year. The values resulting from these figures are compared with the actual data. This is figural displayed in figure 41 and 42.

TABLE 30 – MEASURED DATA ENERGY USE CASE STUDY

		GAS DEMAND [m³]			ELECTRICITY DEMAND [kWh]		
Month		Modelled value - assumption	Modelled value	Actual data	Modelled value - assumption	Modelled value	Actual data
0	January	17.362	16.492	18.300	83.037	113.736	94.031
1	February	16.034	15.230	16.572	81.688	111.888	93.197
2	March	14.631	13.898	14.686	66.108	90.547	90.513
3	April	10.498	7.9.971	9.234	66.405	90.954	89.503
4	May	7.176	6.816	4.850	75.451	103.344	89.133
5	June	5.036	4.783	2.033	75.190	102.987	90.930
6	July	3.707	3.521	310	75.501	103.413	104.016
7	August	3.928	3.731	596	69.653	95.402	83.978
8	September	5.995	5.695	3.295	66.182	90.649	95.313
9	October	7.767	7.377	5.641	66.568	89.971	93.850
10	November	10.941	10.392	9.875	83.396	114.228	93.383
11	December	12.565	11.934	11.984	78.324	107.280	91.481
Total		102.520	97.905	97.376	809.908	1.107.120	1.109.328

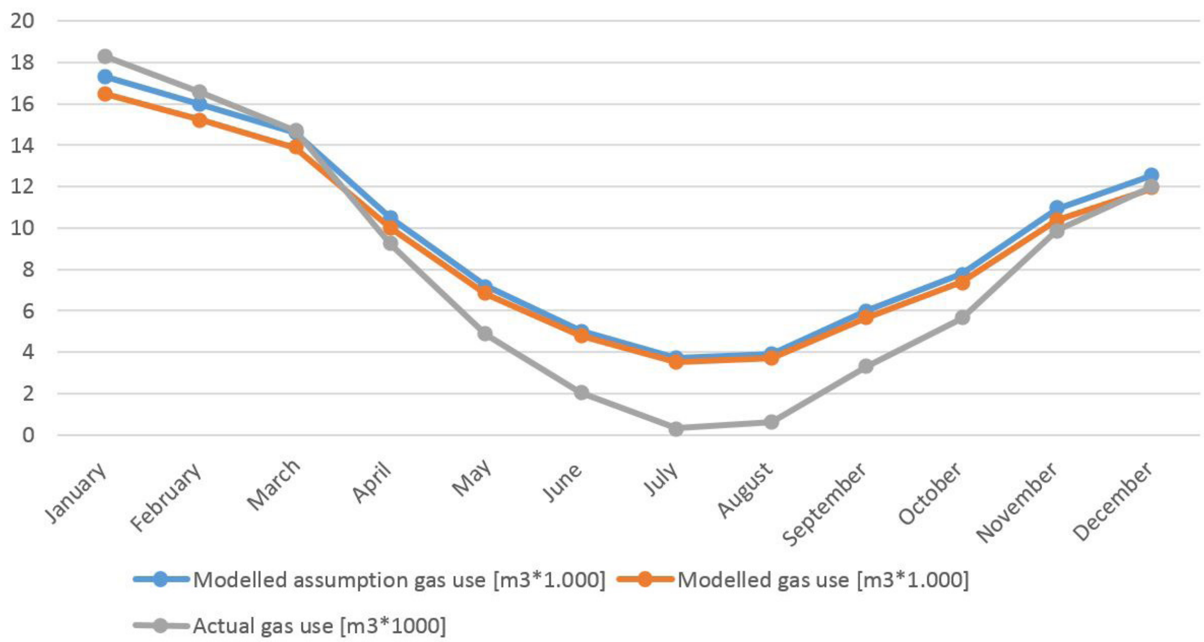

FIGURE 41 VALIDATION INITIAL SITUATION OF THE GAS DEMAND

In figure 41 the modelled assumption of the gas use, the modelled gas use and the actual gas use of the case study is shown. The modelled assumption gas use describes the gas use based on the in chapter 4.3.8 based assumptions if the gas demand is not available. The modelled gas demand is the total actual gas use spread out over a year following a specific curve. The actual gas use is the data gathered from monitoring over a year. From figure 41 can be concluded that the modelled gas use and the modelled assumption of the gas use varies little, which corresponds with the in figure 39 displayed validation. Overall, all three the gas use demands show a little variance which means that both the assumption data as the modelled data is a good representation of the reality.

The main difference can be seen from May till October. Between these months the actual gas use is less than expected in the modelled gas use. This difference can come from several aspects, first of all the average temperature during the months and the employees that are working in the building. However, this is compensated in the modelled gas use by using less gas from January till March. Which means that overall the actual gas demand is the same total as the modelled gas demand.

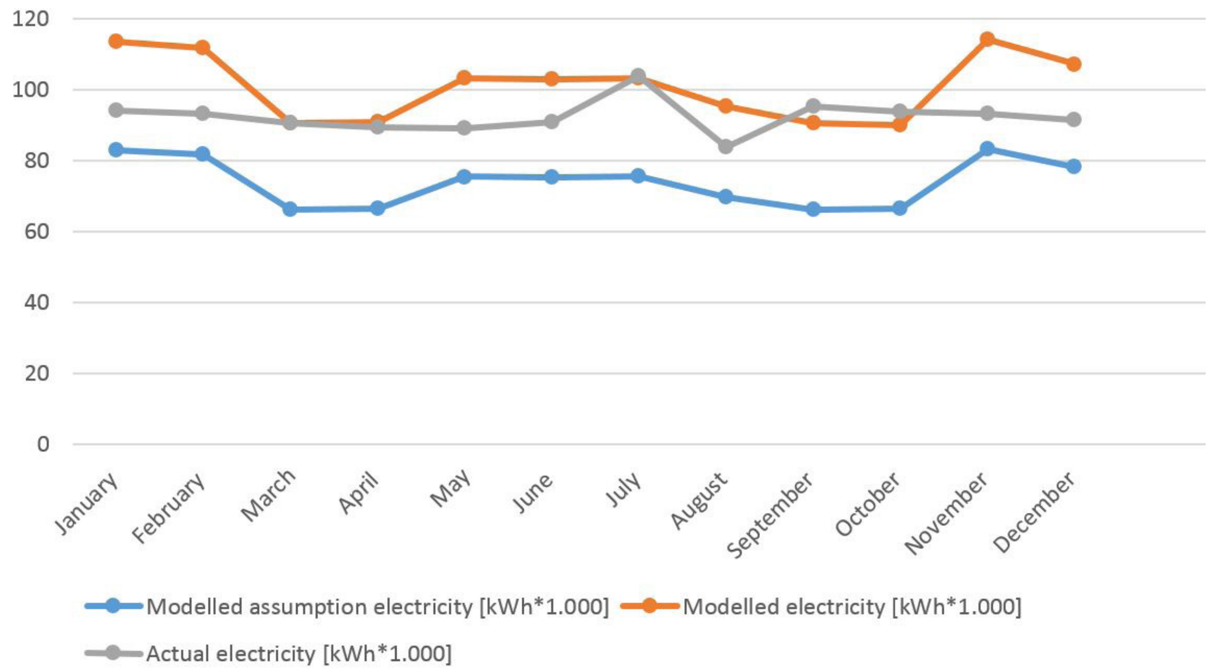

FIGURE 42 VALIDATION INITIAL SITUATION OF THE ELECTRICITY DEMAND

In figure 42 the modelled assumption of the electricity demand, the modelled electricity use and the actual electricity use is shown. The modelled assumption electricity use describes the electricity use based on the in chapter 4.3.8 based assumptions if the electricity demand is not available. The modelled electricity demand is the total actual electricity use spread out over a year following a specific curve. The actual electricity use is the data gathered from monitoring over a year.

As can be seen two lines (e.g. actual electricity and modelled electricity) follow approximately the same line. Overall there are some differences from January till February, April till July and October till December. The actual electricity use of the building follows a more horizontal line whereas the modelled electricity shows a bit more variation. This difference can come from the ventilation demand curve shown in appendix 13, this curve shows the difference which is described above. The modelled assumption shows a bit more variation than the others, overall the electricity use per month is lower than the actual electricity use and modelled electricity use. These differences can come from several aspects. First of all due to the ventilation demand curve shown in appendix 13, this curve shows the difference which is described above. Besides that, the electricity use due to equipment is more than half of all the electricity use. As explained before, the equipment exist mostly of office equipment used by the employers which varies over the year. Also, if the results of monitoring are compared it shows that also by monitoring the electricity per year differs significant from a range of 30%-40% more or 30%-40% less than the average modelled electricity demand, which is explained previously.

4.6.2 Historic data – validation measure package

The energy performance advice (2008) is a report which is based on the EPC calculation method. The report shows a recommended measure package on what to optimize on the case study. The results of this report are compared with the results of the model. The conclusion and recommendation of the report are shown in table 31. Several recommendations have been implemented during the recent years. Besides these measure package list, another improvements was also executed, namely a daylight dependent lighting system, which is here zero. Before discussing the results, the measure package list provided from the energy performance advice provides for an energy label A which means that the measure package will not reach neutrality, but only an energy reduction. Table 31 shows the comparisons of measure packages from the energy performance advice and the measure package generated from the Vensim model.

Step 1.1 building optimization – as can be seen in table 31, the energy performance advice does not recommend the HR+ glazing for the remaining double glazing. As can be seen in the results, the effect of HR+ on the double glazing is very minimum (0.04%). However, for reaching energy neutrality, the building envelope needs to be optimal.

Step 1.2 system optimization – for the system optimization there is an overlap, between sun shading. The difference regarding system optimization is the difference in lighting system, demand controlled ventilation system and dew point cooling. By using a different lighting system than is currently used (9 W/m^2) to a more energy efficient lighting system (3 W/m^2), more energy can be saved. The second difference – demand controlled ventilation system – is advised, but not by the energy performance advice. However, the installation of such a technology has a large impact on the energy demand because there are seldom 100% of the people present of the total capacity of the building. The last difference is the use of dew point cooling, dew point cooling is a renewable energy generation and has an acceptable payback period. This combination of techniques is good fit in both existing and new buildings. However, dew point cooling cannot be implemented within the EPC methodology as a cooling technique which is the reason why it is not used in the report (Lobregt & van der Stoel, 2009).

Step 2 generation on building footprint – both the energy performance advice as the Vensim model show that there is no generation possible on the building footprint.

Step 3 energy generation on-site – for the generation on-site, there is an overlap regarding a gas heating pump both measure packages agree on the fact that a gas heating pump is needed for the generation of heating. The energy performance advice gives an advice for installing an electric heating pump for the cooling of the building. However the Vensim model showed that there is a better solution than an electric heating pump. Step 1.2 shows that a dew point cooling system is better than an electric heating pump. Dew point cooling has a significant better energy efficiency in comparison with an air-conditioning heating pump. The last difference is from the Vensim model, which advises a biomass boiler. Again biomass is not valued positively in the current EPC system, because the efficiency of the plant determines the valuation and not the fuel for meet the energy demands. Which means that biomass scores similar to conventional heating. That makes it almost impossible to comply with the building with such a boiler (Lobregt & van der Stoel, 2009).

Step 4 energy generation off-site – for reaching energy neutrality, off-site generation is needed, however the energy performance advice doesn't go into this aspect, since it is building oriented. The validation of off-site generation is done based on historical data of the KNMI regarding solar hours and wind hours in the Netherlands. All sources of the data can be found in table 32.

Step 5 off-site supply – There is no off-site supply needed in this case. The validation of off-site supply is not needed, since that are the rest streams of energy which need to be bought from energy companies.

TABLE 31 – COMPARISON MEASURE PACKAGES

	Energy performance advice measure package	Vensim model advice measure package
Step 1.1 building optimization		• HR+ glazing
Step 1.2 system optimization	• Sun shading	• Sun shading • **Other lighting** • **Demand controlled ventilation** • **Dew point cooling**
Step 2 generation on building footprint		
Step 3 generation on-site	• Gas heating pump • Electric heating pump	• Gas heating pump • **Biomass boiler**
Step 4 generation off-site		• **Windmill** • **Solar panels**
Step 5 off-site supply		

After the validation of the measure package, the validation of the data is needed. The data is based on sources such as TNO, scientific journals, ISSO, NEN, websites, Heijmans etc. an overview of the validation of the data is shown in table 32. The sources give are the main sources, however all the variables are double checked with other sources.

TABLE 32 – VALIDATION DATA

DATA	SOURCE
Step 1.1 building optimization	
Reduction rate per m^2 cavity wall	Milieucentraal (2015), Duurzaammkb(2014)
Reduction rate per m^2 roof	Milieucentraal (2015), Duurzaammkb(2014)
Reduction rate HR+ glazing	Hadeko trading company (2015)
Step 1.2 system optimization	
Demand controlled ventilation	AgentschapNL (2011), S&P (2014), Duurzaammkb(2014), BRIS (2014)
HR107 gas reduction	Duurzaammkb (2014), European Heat Pump Forum (2010)
Dew point cooling	Lobregt & van der Stoel (2009), NEN 2916, AgentschapNL (2011)
Sun shading	TNO (2008), Bakker, Zonneveldt and van Oeffelen (2011)
Lighting	ISSO (2010), Philips (2010), van der Laan (2010)
Step 2 generation on building footprint	
Solar panels reduction rate	Solsolutions (2015), SenterNovem (2015), Zonne-energie gids (2015)
Solar hours	KNMI (2014)
HRe reduction	Duurzaammkb(2015), SenterNovem (2015)
Step 3 energy generation on-site	
Gas pump efficiency	SenterNovem (2015), GasTerra (2010), Bakker, van der Garde, Jansen, Traversari and Wagener (2010), TNO (2014)
Electric pump efficiency	SenterNovem (2015), GasTerra (2010), TNO (2014)
Bio boiler energy use	Lobregt & van der Stoel (2009)
Heat cold storage	wkotool.nl (2015)
Step 4 energy generation off-site	
Biogas installation	Biomassa.eu (2014), Agentschap NL, 2010, (VHL, 2015)
Biogas incl. cogeneration	Biomassa.eu (2014), Agentschap NL, 2010, (VHL, 2015)
Wind turbine	Duurzame-energiebronnen (2014), Rijksdienst voor Ondernemend Nederland (2012), Windpark.nu (2015)
Full-load hours wind turbine	KNMI (2014)

4.6.3 Expert feedback

Several experts from the expert interviews in the third chapter were consulted by presenting them the model, with the aim of verifying the model and validate whether the model can provide insight in making a building energy neutral. The experts were also consulted to interpret the case study results to see if the model can be understood by other people than the maker.

The following conclusions can be derived from the interviews regarding the model: The main aim of the model is to see if it is possible to reach 0 kWh and 0 m^3 gas from fossil fuels, by optimizing the building and the generation of renewable energy. Based on the output generated by the model, experts agree on the conclusion that the model shows insight whether or not energy neutrality is reached and after which step the building can be stated energy neutral. Besides this feedback, the software package Vensim and the method system dynamics is not familiar in practice, which means that the user interface is helpful as a guide throughout the model. The interface is helpful but that doesn't mean that the experts want to know the effect of each sub step. This means that they want to know and see what discussions are made. Appendix 11 shows that specific, and shows the relations between the different technologies. Throughout the explanation and discussion of the model several remarks were made by the experts and were integrated in the adjustment of the model. For example, the optimization of the ventilation was beforehand described per month, however for the exact determination of the effect of the ventilation it is needed to calculate them per hour, because then the capacity can be determined. Besides that, the subsystem show a realistic view of reduction rates. This model can be the foundation to see whether or not more buildings can be made energy neutral on a larger scale. However, it is a simplified version of all the technologies, but it provides insight of reaching that goal yes or no. The goal can be reached and the model can be elaborated later to provide more detailed information.

The following conclusions can be derived from the interviews regarding the result of the case study: beforehand, the experts said that there is a maximum effect on building and system optimization. This effect is used to check if step 1.1 (building optimization) and step 1.2 (system optimization) show a realistic effect. The experts said that the maximum reduction from building and system optimization was 40%. However, realistic speaking this will be between 15-20% (more for old buildings, and less for relatively new buildings). When this percentage is checked with the case study it show that the case study shows a result within the boundaries. The effect of step 1.1 and 1.2 are 18%, which means the effect falls within range. This means also that the other 82% reduction has to come from generation of renewable energy, which in the case study is also the result. Also the effect of the wind turbine was discussed. They agreed also that it is not possible to generate all the electricity from solely the wind turbine. At this moment, no solar panels on the building footprint and building site are calculated, this is due the fact that the return rate for solar panels has to be less than stated, because the building is not from Heijmans, but Heijmans rents the building. Overall, the measure package list shows a good representation for reaching energy neutrality.

4.7 DISCUSSION AND RECOMMENDATION

The model can be used for gaining insight if a building(s) can be made energy neutral. For this model, only the main technologies are modelled more technologies can be integrated into the model which means the model can stay up to date and keep its dynamic behaviour. The input data for the model can be generated using several methods. The most specific method is monitoring the energy use and cataloging all the building characteristics and is recommended the most, however if this is not a possibility, then assumptions can be made regarding the energy use of the building. In that cases a specific value per square meter can be used to see what the energy of an office building is. Besides that, at this moment some technologies are not modelled due to a high payback time, in the future these technologies can be inserted into the model as well, when the technologies are cheaper. As explained in the causal loop, this model is a small part of a larger relationship between systems. To gain the most benefit out of the software and insight of other variables, further research can be used to model these variables as well. However for this research, those variables are out of bound.

4.8 CONCLUSION

This chapter showed an approach which can be used in order to make building energy neutral, by using SD. By using currently available technologies the system behaviour between the technologies can be identified. All the technologies that are modelled all have a payback time within 10 years, this boundary has been set at the beginning of the chapter. The model can be used by people who are not familiar with the software program Vensim, by using the user interface. When inserting the data gathered from the questionnaire in appendix 16, nonexpert can generate the same results as experts. The end result shows a measure package list which show how to make a building energy neutral. Also, the model can be used to connect more buildings to the off-site generation. The importance of connecting the buildings is that the investments of the off-site generation tools are very high, by splitting the cost the investment in off-site technologies becomes more attractive. The time of filling in the model and the time of generating the results is minimum, which means this tool can also be used as a method to convince other building owners to invest in energy neutrality. In this case, not much money needs to be invested to approach a building owner, due to the minimum time that is needed to fill in and gain results. In conclusion, the main research question can be answered, and it is feasible that an existing building can be made energy neutral.

CHAPTER 5 – CONCLUSION

In the introduction of this graduation thesis, one main research question and five sub questions were stated. In this paragraph the gained insight regarding the thesis questions are discussed, followed by the societal, scientific and beneficiary relevance of the report. This chapter ends with a discussion about the implications, recommendations and limitations of the research.

5.1 CONCLUSION

The research started in the introduction with a main research question and several sub research questions. After these research the questions can be answered and conclusions can be drawn.

RQ1	What is energy neutrality and when is it reached?

The first research question stated above is about what energy neutrality is and when it is reached. In chapter 3 this research question is answered by formulating a clear and consistent definition. Energy neutrality defined as ZEB is 'a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources from on-site supplies and if necessary off-site supplies'. Energy neutrality is reached when there is 0 kWh use of electricity and 0 m^3 use of gas in a year. This means that if a building uses 0 kWh fossil electricity and 0 m^3 fossil gas in a given year and compensates its energy use by renewable energy sources, the building is labelled as energy neutral.

RQ2	What kind of energy improvement tools are available on the market and can be used to make a building energy neutral?
RQ2.1	What kind of energy improvement techniques are available for building specific optimization?

The second research question stated above is divided into two sub questions. The first sub question is about what energy improvement techniques are available within the building footprint. Energy improvement techniques are those techniques that lower the energy loss by different approaches such as prevention of heat leakage (caused by a low insulation value of the building envelope and thermal bridges), or efficient systems which use the needed energy more efficient per measured energy. These energy improvement techniques can be divided two categories, 1) building optimization and 2) system optimization. For the first category, the building can be improved by the reduction of energy loss by the insulation of the cavity wall, roof, floor and windows. For the second category, the current systems of the building can be optimized by installing a demand controlled ventilation system, a HR107 boiler, dew point cooling system, low energy lighting system and sun shading. There are other possibilities regarding building envelope and system optimization, however, they have a lower efficiency rate than the improvement tools stated above.

RQ2	What kind of energy improvement tools are available on the market and can be used to make a building energy neutral?
RQ2.2	What kind of sustainable energy generation techniques are available for on-site and off-site generation?

For the second part of answering question 2, the energy generation techniques are discussed. For the generation of energy there are several possibilities either on-site or off-site. For on-site generation it can be done in two ways, one by using generation technologies within the building footprint or on the building site. For the generation within the building footprint the possibilities are the use of solar energy and the use of a high efficiency boiler (HRe boiler) which uses gas for the heating of the building, but also generates from the gas a part electricity. Again, there are other possibilities for generating energy within the building footprint such as a small wind turbine, however for the example of the wind turbines, the payback time is higher than 10 years and is not used in the model. For the generation on-site, there are three techniques used. The first technique is the use of either a gas heating pump or an electric heating pump. The gas heating pump can be used for the reduction of the heating demand, the electric heating pump can be used for the reduction of the cooling demand. Another approach for the heating and cooling reduction of building is the use of a heat and cold system (e.g. thermal storage), a thermal storage system can reduce the cooling and heating demand significantly. Another technique for the generation of energy is the use of a biomass boiler. The biomass boiler uses wood chips which can generate enough energy for the heating of the building or the heating that is left after the installation of a heating pump or thermal storage. For on-site generation, solar energy can again be used, but then from the generation on the building site.

For off-site generation there are three techniques possible. The first technique is the use of a biogas installation. This can be done in two ways, if there is both a gas demand and electricity demand left a biogas installation with cogeneration can be used to generate both electricity as gas. If there is only gas left, then a normal biogas installation for the generation of gas can be used. The second option is the generation of electricity with the help of wind energy, by using a wind turbine. And again, solar energy can be used for off-site generation as well.

RQ3	What are the limitations regarding energy reduction based on energy efficiency and indoor climate requirements?

The limitations regarding energy and climate requirements is discussed in chapter 3.4.2. This chapter described the indoor climate measures based on the demand of the people within the building. The main reason for indoor climate is thermal comfort and an overall well-being which increases the productivity of the people working in the office buildings, but prevent an optimal energy reduction (e.g. limitation). The main measure criteria are the operative temperature and the maximum airspeed in the building. Also, besides the indoor climate requirements, several limitations about the building envelope optimization are brought forward. There are also restrictions / limitations in the optimization and the effect is has on the reduction of the energy loss (e.g. efficiency). The main part is in the building insulation, all are described in chapter 3.4.1.

RQ4	How can the tools gathered from sub question 2 and 3 be used, so that it is usable for modelling?

The information gathered from sub question 2 and 3 have both a different effect in the model. Sub question 2 are the techniques which needs to be modelled, where sub question 3 provides for a boundary of the techniques and are not modelled explicitly. If the boundaries are not met from question 3, then the techniques who do not meet the boundary, are not modelled. The techniques are modelled based on their requirements. The techniques can be used based on their limitations of usage, for example if there are circumstances when a technique is better not used it will give a result of zero. Also, what is the energy reduction of the technique and what effect has the energy reduction over a year time? Are there months where more energy is reduced than in other months? That are the main questions that are answered in chapter 4.

RQ5	How can the usable technologies be combined so that a model can be made in order to simulate the energy usage of an existing building?

The techniques described in chapter 4 can be dependent on each other or are interdependent. The combination of the technologies is based on what demand they reduce. For the heating of the building there are three options, first the reduction in heating is done by interdependent techniques such as insulation and sun shading. The second option is the possibilities regarding a heating system (HR107 boiler, HRe boiler and a biomass boiler). And a last option is regarding heating generation (gas heating pump, heat cold storage, biogas – cogeneration and biogas). For cooling, sun shading is also effective. For the generation of cooling energy there are three options; dew point cooling, heating pumps or heat cold storage. For both ventilation and lighting there are only separate technologies possible such as sun shading, new lighting and demand controlled systems. As last, the generation of electricity can be done by using either solar panels, wind turbines, biogas installation or a HRe system. A biogas installation is mostly used when there is a gas demand left, because the system generates gas. Appendix 11 describes per demand (e.g. heating, cooling, and electricity) what the relationship is between the technologies.

RQ	'What is the feasibility of the energy neutrality in existing office buildings with current instruments?

After all the sub research questions are answered, a final answer can be given the main research question stated above. It is feasible to reach energy neutrality within existing office buildings with current instruments. The case study showed that is possible for an office building to reach neutrality. In the case of the case study, energy neutrality is reached from step 4, off-site generation. In many cases it will not be possible due to on-site situations to reach energy neutrality within the building site. If that is the case, then off-site generation is needed to reach energy neutrality. The model showed that it is possible to connect a building to off-site generation and reach neutrality. A next step can be to connect more buildings and lower the overall investment cost of the off-site generation techniques. This research showed a bottom-up approach for making existing office buildings on – first – a small scale energy neutral.

The model is also easy in use. For the people who do not know Vensim, the model can be used by using the user interface. The information that is needed for the model, can be generated by using the questionnaire in appendix 16 and then fill in the user interface with the help of appendix 14. Then after the simulation, the output window shows the results and measure package for the specific building.

The strength of this model is that by using System Dynamics the model will be adaptive, if there is a new tool available it can be inserted into the model. Also, each building with its specific characteristics can be inserted and provide the building with a building specific optimization list, which makes the building energy neutral.

5.2 SOCIETAL RELEVANCE

One of the major causes of climate change is the energy use of human activity and in specific the build environment. The built environment accounts for approximately 35% of the total Dutch energy consumption. More than half of this part is used in commercial buildings such as schools and offices (Agentschap NL, Infoblad energieneutrale scholen en kantoren, 2012). Where 80% of the CO_2 emissions is caused by the operating phase of the existing buildings.

As part of this problem, this research tried to find a solution for reaching energy neutrality within the build environment and in specific, office buildings. By making office buildings energy neutral, the overall CO_2 emission will lower and will have a positive impact on the changing climate. There is overall no approach yet for making buildings on a larger scale energy neutral, this research also has potential for a bottom-up approach for reaching energy neutrality on larger scale. This approach will have a larger impact on the overall lowering of the CO_2 emission than buildings separately.

5.3 SCIENTIFIC RELEVANCE

The concept of the Zero Energy Building has gained a lot of attention over the years in the scientific literature. However, there is little consistency regarding Zero Energy Building. There are many approaches used in different views and contexts. With the gaining attention, Zero Energy Building requires a clear and consistent understanding and approach. This research aims to clarify what zero energy building is and what approach needs to be used. By combining the existing information in the literature and using expert feedback, a new definition can be formed. Throughout this research a clear and consistent Zero Energy Building definition is proposed including boundaries and a framework which can be used as an overall guideline for reaching energy neutrality.

Zero Energy Buildings have many advantages, especially in terms of comfort, operation and environment. The need for energy-neutral building and renovate increases sharply, not only because of climate change but also because of the looming shortages (affordable) fossil energy in conjunction with the ‘supply’.

Existing scientific articles mainly focuses on how new buildings can be build energy neutral with the help of several tools such as life cycle assessment. But the fact is that the majority of the buildings is already build. The researches that focuses on existing buildings mainly use assessment of current building stock, but these do not provide an answer on how current tools can be used to make existing buildings energy neutral and provide a building specific answer to the question: ‘how can is make this building energy neutral with the help of existing tools?’.

Besides these scientific articles, already there are several tools available to gain insight into environment impact of buildings. The two most known tools in the Netherlands are BREEAM and ‘GRP gebouwen’. Both are assessment methods to determine the environmental impact of buildings. Based on a standard for sustainable building, it indicates the performance level of a building. The missing factor in these tools is that they only look at energy savings and give quantitative weight on the performance. The missing factor is the look on how can the tools be combined in an optimal why as such that the buildings becomes energy neutral. This research fills that gap and focuses only on how the fossil energy consumption can be lowered to zero with the help of current available tools.

5.4 BENEFICIARY RELEVANCE

With the contours of the future, Heijmans expresses the ambition to be the best builder in the Netherlands, by improving and renewing from social relevance. This ambition is translated for technology to the following principles:

- The buildings that Heijmans makes deliver ENERGY
- Heijmans creates and adapts to new MATERIALS
- Heijmans solutions deliver on SPACE
- Heijmans develops inspiring KNOWLEDGE
- Heijmans provides smart TECHNOLOGY that adds value
- Heijmans customers and users are satisfied

This research is performed as part of the first principle, the buildings that Heijmans makes, deliver energy. This research identified a method in gaining insight in energy-saving solutions for their office buildings. This model can be used as a bottom up approach for making office buildings on a large scale energy neutral. At this moment, only one building is implemented into the model, however more buildings can be connected which makes splits the investments of off-site generation technologies with the other buildings that can be connected with this model. This means for Heijmans that the buildings Heijmans makes (in this case renovates) can reach neutrality and is a method to realize the first ambition.

Besides that, Heijmans can use this model in another way. Heijmans can insert their clients' buildings into the model and see what needs to be done to reach energy neutrality. With this measure package list per client, Heijmans can approach their clients and see whether or not they are interested in making their building energy neutral and show that by working with other building owners, the investment of the more expensive technologies lowers significant. This model can function as basis for convincing their clients that it is possible to reach energy neutrality. This model takes minimum time and capacity to insert a building and show the results. This method is a simplification of all the energy reduction technologies and renewable energy generation technologies, but it is enough to convince the client, and persuade them into a contract where Heijmans, will further explore the described possibilities.

5.5 DISCUSSION

5.5.1 Practical implications and recommendations

The research started with gaining an overall definition of ZEB. Throughout the literature, a new adjust definition is formulated which could be used as an overall definition. Previous, there was no common agreement on the definition of ZEB, but this definition could be tested and eventually be used as a common definition. The methodology of reaching ZEB explained in this research however, cannot be used as an overall guideline. The reason for this is that the steps are specifically made in the context of existing office buildings. Each context can require a different methodology.

The second part of the research showed with the help of the software package Vensim how to create a model which shows whether or not a building can be made energy neutral. At this moment it is possible with this model to make a building energy neutral and see after which step (e.g. building optimization, system optimization, generation on building footprint, generation on-site and generation off-site) the building is energy neutral. The model gives an overview of the total reduction of each step and even of each technology. The user interface can be used for people who do not know the software package by inserting the required data (gathered from the questionnaire) into the user interface.

This model can be used to show in a minimum amount of time whether or not neutrality is possible for a building, and if so, how it should be made neutral. Which means that this model can be used in practice for building companies to convince their clients that neutrality is possible and if they are willing to cooperate with the building company, without investing much time and money. If the client cooperates, the building company can enter a contract to further develop and elaborate on the simplified version of this model. But now they have the resources to do that.

5.5.2 Limitations and directions for further research

The following limitations were identified that influence the results and generalizability of the research. As told in chapter 5.5.1, the stated ZEB definition can be used as an overall definition, but the methodology differs per context. This means that the translation and methodology stated in this research can only be applied on the context of existing office buildings.

For the model there are also limitations that influence the results of this research. Due to a limited time frame the focus of the techniques was on the main available techniques. This means that neutrality is reached with only using those techniques. However, there are other possibilities that could be applied, but are not modelled at this moment. This means that for further research, other less known techniques also should be modelled to give a more broad display of the techniques that are available. The benefit of this model is that it can be adjusted, however it should be done by someone who knows the software package. Also, some techniques are not modelled at this moment due to a too high payback time, in the future these techniques will lower in payback time and can be used in this model. If that is the case the model can be adjusted and the techniques can be modelled.

Furthermore, the research was aimed at answering the main research question on whether or not it was feasibility to reach neutrality within existing office buildings. In order to do that, the techniques are modelled using standardized data, which means as explained in chapter 5.5.1, that this model can be used to show that neutrality is possible, but further research and elaboration of the techniques is needed to show the real-time results of each technology for a building.

At this moment only one building is inserted into the model, however it is possible to connect more buildings in this model. This can be done by copying the first 3 steps (energy reduction of each building, energy generation from building footprint and site) and connect them with step 4, generation off-site. In that case the investment cost of the techniques in step 4 will reduce significantly and more buildings can profit from the energy that is left. This can be done for further research, where a certain area of office buildings is modelled and see if an area can be made energy neutral). It is possible that there is a maximum between the buildings that can be connected in this model to the off-site generation tools. For further research, this is interesting to find out. An approach for finding this optimum is looking at a balance of renewable energy generation and energy consumption of the buildings. What is the balancing point where the most buildings profit from renewable energy generation? This can be based on different aspects such as investment costs, amount of users which use a type of off-site generation, location specifications (e.g. limitations area) etc.

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APPENDICES

APPENDIX 1 – QUESTIONNAIRE INTERVIEW

INTERVIEW – ONDERZOEK NAAR MOGELIJKHEID TOT ENERGIENEUTRALITEIT BINNEN BESTAANDE UTILITEITSGEBOUWEN

Naam:

Functie:

Datum interview:

Inleiding

Voor mijn afstudeerproject ben ik onderzoek aan het doen naar de mogelijkheid om bestaande utiliteitsgebouwen – en specifiek kantoorgebouwen – energieneutraal te maken. Hiervoor ben ik als eerste een onderzoek aan het doen naar de betekenis van energieneutraliteit en welke elementen hier o.a. het meest belangrijk in zijn. Om tot een goede betekenis van energieneutraliteit te komen wil ik graag door middel van interviews tot een goede betekenis komen door informatie vanuit de praktijk en theorie te combineren. Het uiteindelijke doel is om een model te creëren waarin de gegevens van een bestaand kantoorpand ingevoerd kunnen worden en vervolgens door middel van een simulatie een gebouw specifiek advies tot energieneutraliteit eruit volgt.

Algemene vragen

1) Wordt er op dit moment binnen Heijmans gefocust op energiebesparing of energieneutraliteit?

2) Is energieneutraliteit ook daadwerkelijk haalbaar volgens u?

3) Bij welke soort bouw (nieuwbouw en bestaande bouw) wordt momenteel energiebesparing en/of energieneutraliteit toegepast?

4) Welke meetmethode wordt toegepast om energiebesparing en/of energieneutraliteit te berekenen? (bijv. BREEAM, GPR gebouwen, EPG etc.)

5) In hoeverre wordt er energiebesparing gecreëerd ten opzichte van de oude situatie? (bijv. 20%-80% besparing t.o.v. oude situatie)

Aspecten met betrekking tot energiebesparing en/of energieneutraliteit

6) Wat is het hoofddoel met betrekking tot energiebesparing en/of energieneutraliteit? (bijv. CO2 emissie verlagen, energie kosten besparen, total cost of ownership, maatschappelijk verantwoord ondernemen etc.)

7) Door middel van welke toepassingen wordt het doel van vraag 6 bereikt? (bijv. gebouwoptimalisatie, grid connectie, inzicht energieverbruik etc.)

8) Waar gaat de voorkeur naar uit met betrekking tot energiebesparing / energieneutraliteit, duurzame energie op gebouw terrein of juist buiten het gebouwterrein?

9) Vanuit welk niveaus wordt een gebouw verduurzaamd m.b.t. energie?

   a. Gebouw specifieke optimalisatie (bijv. (na-)isoleren, dubbel glas, installatie optimalisatie etc.)

   b. Automatiseren binnenklimaat gebouw

   c. Duurzame energieopwekking op gebouwterrein zelf (bijv. WKO, zonnepanelen etc.)

   d. Duurzame energieopwekking buiten het gebouwterrein (bijv. d.m.v. gebieds-ontwikkeling, waarbij gezamenlijk gebruik gemaakt wordt van energieopwekkende bronnen)

   e. Duurzame stroom via stroomleverancier

   f. Overige, namelijk:

10) Welke elementen zijn volgens u het meeste van belang om energieneutraliteit te bereiken?

Onderzoek specifieke vragen

Tijdens mijn onderzoek naar de definitie van energieneutraliteit ben ik vier definities tegen gekomen in wetenschappelijke artikelen. Graag wil ik u hier een aantal vragen over stellen. Allereerst een korte uitleg van de 4 verschillende definities:

- Metrisch evenwicht van energie neutraliteit – De toegepaste eenheid voor de "nul" evenwicht wordt beïnvloed door een aantal specifieke maatregelen waaruit de definitie wordt bepaald. O.a. het projectdoel, intenties investeerders, klimaat/uitstoot broeikasgassen, energiekosten en overheidsmaatregelen liggen ten grondslag aan de definitie.
- Energieneutraliteit aan de hand van klimaat gegevens – energieneutraliteit wordt bereikt aan de hand klimaat specifieke gegevens. In deze methode wordt er gekeken naar de sterke punten van een land (bijv. sterke wind, veel zonuren etc.) om vervolgens deze sterke punten te gebruiken in het toepassen van duurzame energieopwekking zoals zonne-energie en windenergie.
- Periode van energieneutraliteit – energieneutraliteit kan alleen worden bereikt worden door de gehele levensduur van een gebouw in acht te nemen. Energieneutraliteit wordt dan vertaald als de primaire energie die gebruikt wordt in de realisatie-, operationele-, en sloop fase over de levensduur van het gebouw, welke gelijk is aan de energie die geproduceerd wordt door duurzame energie systemen over de levensduur van het gebouw.
- On-site en off-site energieneutraliteit – energieneutraliteit kan bereikt worden op twee manieren. Door middel van op het terrein aanwezige energievoorziening vanuit hernieuwbare energiebronnen die beschikbaar zijn binnen de footprint van het gebouw zijn (bijv. PV panelen, windenergie op gebouwterrein etc.). Of door het gebruik van hernieuwbare bronnen beschikbaar buiten het gebouwterrein om energie op de site te genereren of hernieuwbare energie bronnen (bijvoorbeeld biomassa, PV buiten terrein etc.)

11) Aan de hand van de hierboven gegeven definities, wat is volgens u in de praktijk het beste toepasbaar qua definitie?

    a. Metrisch evenwicht van energie neutraliteit (terrein-, bron-, energiekosten-, emissie energieneutraliteit)

    b. Energieneutraliteit aan de hand van klimaat gegevens

    c. Periode van energieneutraliteit

    d. On-site en off-site energieneutraliteit

    e. Combinatie van volgende definities:

12) Wat verstaat u onder energieneutraliteit?

13) Om tot een goede balans te komen moeten ook de standaard gebruiken van de gebruiker veranderd worden. O.a. om een constante temperatuur in het gebouw realiseren en het gebruik van elektriciteit van externe apparaten (printers e.d.), tot in hoeverre kan Heijmans deze gebruiken beïnvloeden?

EINDE INTERVIEW, HARTELIJK DANK VOOR U TIJD.

APPENDIX 2 – REPORT INTERVIEW D. TIMMERMANS

Verslaglegging zakelijke weergave expertinterview 1

Datum : 9 maart 2015 Tijd : 13:00 – 14:00, 1 uur Naam expert : D. Timmermans Functie expert : Business development manager - technology Bedrijf : Heijmans utiliteit Interviewer : E. van Oosterhout Plaats interview : Rosmalen

1 Algemene vragen

1.1 Wordt er op dit moment binnen Heijmans gefocust op energieverduurzaming of energieneutraliteit?

Focus energiebesparing of energieneutraliteit volgt vooral uit de vraag van de opdrachtgever (vraag gestuurd uit de markt). Op dit moment worden alleen door middel van renovatieprojecten worden gebouwen verduurzaamd. Kennis wordt vooral ingezet op energiebesparing. Wat eigenlijk zou moeten is vanuit Heijmans de klant benaderen en een pakket van maatregelen klaar te hebben liggen om het gebouw energieneutraal te maken. Focus voor energieneutraliteit binnen Heijmans is niet op gebouwniveau, maar op het gebouw en zijn omgeving.

1.2 Is energieneutraliteit ook daadwerkelijk haalbaar volgens u?

Het is haalbaar, hangt af van de business case. Opdrachtgever moet wel de investering terug verdienen. Hierdoor moet vaak de business case verder getrokken worden dan alleen het gebouw, hierbij moet er ook naar de omgeving gekeken worden. Daarnaast is het zo op het gebied van groene stroom, dat zolang de prijs van fossiele energie aantrekkelijker, wordt er weinig/geen gebruikt gemaakt van groene stroom.

1.3 Bij welke soort bouw wordt momenteel energiebesparing of energieneutraliteit toegepast?

Bestaande bouw wordt op dit moment energiebesparing toegepast door middel van renovatieprojecten. Hierbij is het doel (energiebesparing/ energie- neutraliteit) vanuit de opdrachtgever gespecificeerd. Per 2020 is het doel om alles energieneutraal te bouwen/ renoveren. Dit kan wel kenbaar gemaakt worden aan de opdrachtgever, maar dit moet dan ook wel wat opleveren. Binnen nieuwbouwprojecten wordt energieneutraliteit wel toegepast.

1.4 Welke methode wordt toegepast om energiebesparing/ energieneutraliteit te bereiken?

Hangt af van het ontwerpmiddel dit kan beide methodes zijn, zowel BREEAM, GPR gebouwen als EPC. Wettelijk gezien wordt EPC gebruikt bij renovatie, omdat er aan richtlijnen voldaan moet worden.

1.5 In hoeverre wordt er energiebesparing gecreëerd ten opzichte van de oude situatie?

Is afhankelijk van de gebouw specifieke mogelijkheden. Daarnaast hangt het ook af van de ambitie van de opdrachtgever. Hierin kan de opdrachtgever wel gestuurd worden, maar hangt ook weer af van welke organisatie.

2 Aspecten met betrekking tot energiebesparing / energieneutraliteit

2.1 Welke begrip is het hoofddoel met betrekking tot energieverduurzaming/energieneutraliteit?

Vanuit Heijmans en de contouren van morgen mag een gebouw geen energie meer onttrekken uit te omgeving. Belangrijkste aspecten hierin zijn CO_2 emissie en energiekosten.

2.2 Waar gaat de voorkeur naar uit met betrekking tot energiebesparing /energieneutraliteit, duurzame energie op gebouwterrein of duurzame energie buiten gebouwterrein?

Er moet meer gekeken worden naar energiebesparingen in de omgeving en kijken wat er vanuit de omgeving te bieden is. Bij energie reductie en vooral opwekking is grid-connectie van belang (SMART grid). SMART grid op bestaande gebouw is op dit moment te duur. Alle partijen binnen het grid moeten hierin investeren en is afhankelijk van samenwerking met de omgeving. Utiliteitsgebouwen zijn vooral vraag gestuurd.

2.3 Welke elementen worden toegepast om een gebouw te verduurzamen?

Eerste stap: passieve systemen van de gebouwschil. Volgende stap is installatiesystemen bekijken en vernieuwen. Bij het automatiseren van het binnenklimaat is het belangrijk om te weten dat hoe meer comfort je wilt hoe meer energie het kost. Comfort is daarom geen goede graatmeter om te verbeteren. Comfort 'verslechteren' is beter om energie te besparen. Daarnaast is er nog een aspect van belang en dat is het in kaart brengen van materialen. Op dit moment moet bij nieuwbouw een index gegeven worden over welke materialen er gebruikt zijn, hier zijn echter nog geen richtlijnen aan gegeven maar dit kan nog komen.

2.4 Welke elementen zijn volgens u het meeste van belang om energieneutraliteit te bereiken?

(1) de wetgever om in actie te komen, (2) het business model m.b.t. de terugverdientijd en (3) PR, hierbij is het vooral van belang dat een bedrijf kan laten zien dat het een groen bedrijf.

3 Onderzoek specifieke vragen

3.1 Aan de hand van de hierboven gegeven definities, welke is in de praktijk het beste toepasbaar?

Hoe breder er naar gekeken wordt hoe meer mogelijkheden er zijn. Echter sommige situaties zijn gelimiteerd en is een specifiekere formulering noodzakelijk.

3.2 Wat verstaat u onder energieneutraliteit?

Binnen de cirkel rondom het gebouwterrein, mag er niks meer onttrokken worden uit de omgeving. Dit levert echter wel aandachtspunten op. Het is idee is dat mensen niets negatiefs meer kunnen zeggen over de omgeving.

4 Model specifieke vragen

4.1 Om tot een goede balans te komen moeten ook de standaard gebruiken van de gebruiker veranderd worden. O.a. om een constante temperatuur in het gebouw realiseren en het gebruik van elektriciteit van externe apparaten (printers e.d.), in hoeverre kan Heijmans deze gebruiken beïnvloeden?

Inzicht vergaren in het energieverbruik door middel van apps, datasystemen en monitoring om het bewustzijn te vergroten bij de opdrachtgever. Dit zorgt ervoor dat mensen meer bewust zijn van hun energieverbruik. Een andere methode binnen utiliteitsgebouwen is serieus gaming, hiermee worden mensen spelenderwijs bewust gemaakt van hun gebruiken. Vooral domotica en automatisering zorgen voor verlaging.

APPENDIX 3 – REPORT INTERVIEW T. SMITS AND P. KOCH

Verslaglegging zakelijke weergave expertinterview 2

Datum : 10 maart 2015
Tijd : 09:00 – 10:00, 1 uur
Naam expert : T. Smits en P. Koch
Functie expert : Duurzaamheidcoördinator en adviseur energie en xduurzaamheid
Bedrijf : Heijmans woningbouw & vastgoed
Interviewer : E. van Oosterhout
Plaats interview : Rosmalen

1 Algemene vragen

1.1 Wordt er op dit moment binnen Heijmans gefocust op energiebesparing en/of energie-neutraliteit binnen bestaande utiliteitsgebouwen?

Vanuit Heijmans wordt er op het gebied van woningen verder gekeken dan energieneutraliteit in het kader van 'de contouren van morgen' moeten de gebouwen in 2020 energie gaan opleveren. Een gedeelte van de vraag vanuit de opdrachtgevers is energieneutraliteit, deze vraag groeit. Energiebesparing is moeilijker te definiëren, is het besparing als de richtlijnen een EPC 0.6 eisen? Een groot verschil tussen utiliteitsbouw is dat woningbouw vaak ook ontwikkelaar is. Dit betekend dat Heijmans veel eerder betrokken wordt. Hierbij is er meer inspraak mogelijk tussen gemeente en Heijmans. Energiebesparing moet in context gezet worden van zijn omgeving, als energieneutraliteit in de context past dan pas toepassen.

1.2 Is energieneutraliteit ook daadwerkelijk haalbaar volgens u?

Ja, geen enkel probleem. Het probleem is echter dat het nog niet haalbaar is, er is geen sluitende business case deze komt er echter wel. Kosten-baten sluiten op dit moment nog niet aan. Daarnaast herkent de consument nog niet de waarde van energieneutraliteit en hecht er nog geen waarde aan. Collectief bewustwording is hier dan ook belangrijk, waarbij het op korte termijn denken omgezet wordt naar het lange termijn denken. Bij gebiedsontwikkeling wil iedereen meewerken zolang de business case interessant is voor de consument. Nadeel met utiliteitsgebouwen is echter dat het energiegebruik en behoefte van de functie van het gebouw varieert afhankelijk van de functie (bijv. kledingwinkel en supermarkt). Bij gebiedsontwikkeling is het belangrijk dat er rekening gehouden wordt met volatiliteit. Om tot energieneutraliteit te komen is het belangrijk dat de kosten en baten gelijk zijn. Dit kan alleen bereikt worden door de prijs van fossiele energie omhoog te schroeven en duurder te maken als groene energie. Op dit moment zijn de kosten te hoog en baten te laag. Daarnaast moet er goed rekening gehouden worden het 'not in my backyard' concept, iedereen vind dat het moet, maar niet in mijn omgeving waar ik er last van heb.

1.3 Bij welke soort bouw wordt momenteel energiebesparing of energieneutraliteit toegepast?

Er wordt door Heijmans wel energieneutraliteit aangeboden, dit wordt echter nog niet toegepast. De reden hiervoor is dat de kosten en baten niet sluitend zijn. Waarbij de kosten op dit moment te duur zijn.

1.4 Welke methode wordt toegepast om energiebesparing/ energieneutraliteit te bereiken?

Voor woningbouw wordt er voornamelijk gebruik gemaakt van EPG en PAPP (passief huis methode). BREEAM en GPR zijn breder dan alleen energie.

1.5 In hoeverre wordt er energiebesparing gecreëerd ten opzichte van de oude situatie?

Het meest voorkomende energiebesparingspercentage is 40%. Voornamelijk door schil-, verwarming- en ventilatie optimalisatie. De belangrijkste reden hierachter is dat in de woningbouw gewerkt wordt met energielabels en met 40% besparing wordt een label van B bereikt. Bij institutionele beleggers is een BREEAM certificaat van belang m.b.t. verduurzaming.

2 Aspecten met betrekking tot energiebesparing / energieneutraliteit

2.1 Welke aspecten zijn belangrijk en worden meegenomen bij energiebesparing/ energieneutraliteit?

Total Cost of Ownership (TCO) in het geval van woningbouw. Hierbij is van belang dat de investering terugverdient wordt binnen een afzienbare tijd (op dit moment 5-10 jaar). In het geval van de consument is vooral belangrijk dat als eerste de energiekosten omlaag gaan en inzicht in energiegebruik. Bij woningbouwverenigingen zijn ook de energiekosten het belangrijkst vervolgens inzicht in energiegebruik.

2.2 Waar gaat de voorkeur naar uit met betrekking tot energiebesparing /energieneutraliteit? Duurzame energie op gebouwterrein of duurzame energie buiten gebouwterrein?

Beide opties worden opengehouden, echter er is wel een voorkeur vanuit de eindconsument om zo min mogelijk met andere te maken te hebben. De consument wil keuzevrijheid houden, bij gezamenlijke energievoorziening moet er vaak voor 30 jaar getekend worden. Echter voor utiliteitsgebouwen ligt dit anders en is het geen probleem om voor een langere tijd een contract te tekenen.

2.3 Welke elementen worden toegepast om een gebouw te verduurzamen?

Er moet goed op gelet worden dat elk gebouw uniek is. Elk gebouw vraagt een andere aanpak, dat er toevallig overeenkomsten zijn in methodes wil niet zeggen dat het gestandaardiseerd kan worden. Duurzame stroom via stroomleveranciers is voor de eindgebruikers waarmee Heijmans niks te maken (mag) hebben. Automatiseren binnenklimaat is voor woningen alleen op het gebied van de thermostaat en de ventilatie. Hierbij is het van grootst belang dat de gebruiker (ongeacht woningbouw of utiliteit) zelf nog de mogelijkheid heeft dat hij aan de knoppen kan draaien (bijv. raam open zetten, thermostaat regelen etc.). Psychologisch component is zeer belangrijk, ongeacht of een oplossing beter is. Als een technologie niet goed wordt gecommuniceerd met de consument maar opgelegd, zal de consument het nooit accepteren.

2.4 Welke elementen zijn volgens u het meeste van belang om energieneutraliteit te bereiken?

Door middel van wetgeving op Europees, landelijk en lokaal niveau. Het is belangrijk dat er een pragmatische wetgeving komt. Op dit moment worden vooral dogmatische maatregelen genomen. Er moeten juist geen verplichtingen opgelegd worden op uitvoering, maar alleen focussen op een resultaat gerichte aanpak en wetgeving. Daarnaast is er een verandering gaande in de wetgeving waarbij nu de wetgeving naar lokale gemeente gaat, hierdoor zal een wirwar van regels ontstaan waarbij elke gemeente zijn eigen regels heeft.

3 Onderzoek specifieke vragen

3.1 Aan de hand van de hierboven gegeven definities, welke is in de praktijk het beste toepasbaar? (e.g. metrisch evenwicht, energieneutraliteit aan de hand van klimaat gegevens, periode van energieneutraliteit of on-site en off-site energieneutraliteit)

Op dit moment wordt 'nul op de meter' een belangrijk gebruikt gegeven, echter hierbij wordt de context niet meegenomen. Daarnaast is het echter niet mogelijk om op gebouwniveau overal 'nul op de meter' te krijgen. Het kan echter interessanter zijn om een aantrekkelijk energieniveau te krijgen. Het doel: een goede planeet gaat via dit concept voorbij. Het gaat er niet om welke definitie er gebruikt wordt, als er maar 1 definitie is die iedereen begrijpt en waarbij genoeg vrijheid gegeven wordt door middel van pragmatische wetgeving.

3.3 Wat verstaat u onder energieneutraliteit?

Geen mening, het maakt niet uit op welk niveau. We moeten steeds energiezuiniger bouwen om de planeet minder te belasten. Op welke manier dat gebeurt, maakt niet uit. Heijmans stuurt aan op een pragmatische aanpak, resultaat gericht i.p.v. via regels. Eenduidige definitie is niet van belang, we moeten toch steeds zuiniger bouwen. Er moet een gezamenlijk referentiekader zijn, uitvoering niet.

4 Model specifieke vragen

4.1 Om tot een goede balans te komen moeten ook de standaard gebruiken van de gebruiker veranderd worden. O.a. om een constante temperatuur in het gebouw realiseren en het gebruik van elektriciteit van externe apparaten (printers e.d.), in hoeverre kan Heijmans deze gebruiken beïnvloeden?

Beïnvloeding van mensen heeft weinig effect, bij 80% werkt het maar voor even en vervallen vervolgens weer in het oude ritme. Het is bij een kleine groep efficiënt. Dit komt o.a. dat de Nederlandse energie te goedkoop en te betrouwbaar is, dit zorgt er voor dat de mindset van mensen niet verandert. Daarnaast moet er goed rekening gehouden worden met het gebruik van de gebruikers. Als een gebouw goed verduurzaamd is, wil de persoon dat het binnenklimaat optimaal blijft, wat voor energieverbruik verhoging zorgt. Kortom optimalisatie kan leiden tot meer energieverbruik. Het idee kan er zijn dat als het gebouw energiezuinig is, het energiegebruik er niet meer toe doet.

APPENDIX 4 – REPORT INTERVIEW K. DORST

Verslaglegging zakelijke weergave expertinterview 3

Datum : 11 maart 2015
Tijd : 10:00 – 11:00, 1 uur
Naam expert : K. Dorst
Functie expert : Bedrijfsadviseur
Bedrijf : Heijmans utiliteit
Interviewer : E. van Oosterhout
Plaats interview : Rotterdam

1 Algemene vragen

1.1 Wordt er op dit moment binnen Heijmans gefocust op energiebesparing en/of energie-neutraliteit binnen bestaande utiliteitsgebouwen?

Energiebesparing wordt nu gedaan door een gedetailleerde energiemonitoring van alle eigen panden. Hiermee zijn we begonnen in 2008 als een six sigma project. Deze energie monitoring is in combinatie met de huismeesters een tool om inzicht te krijgen in het verbruik. Tevens zijn er energielabels gemaakt van enkele gebouwen om de status van het gebouw aan te tonen en eventuele besparende maatregelen te kunnen uitvoeren. Er is van enkele panden een energiebesparingsplan gemaakt om ook met de oudere gebouwen aan de slag te kunnen. Energieneutraliteit wordt over nagedacht, maar nog niet daadwerkelijk uitgevoerd. Probleem: te hogen investeringskosten t.o.v. baten.

1.2 Is energieneutraliteit ook daadwerkelijk haalbaar volgens u?

Energieneutraliteit is door K. Dorst onderzocht bij het nationaal militair museum om een balans te vinden tussen de gebouw gebonden installaties en opwekking. Deze wordt meestal afgeketst door de investering en de (on)mogelijkheden van het terrein. Kortom, het is wel mogelijk, maar op dit moment zijn de investeringskosten te hoog om het daadwerkelijk uit te voeren.

1.3 Bij welke soort bouw wordt momenteel energiebesparing of energieneutraliteit toegepast?

Energiebesparing kan het beste worden toegepast bij bestaande bouw, hierbij zijn verbeteringen uit het verleden realistischer en kan soms met een eenvoudige ingreep en kosten input worden gerealiseerd. Bij nieuwbouw en renovatie kan met nieuwe technieken gebouwen meer energieneutraal worden gemaakt.

1.4 Welke methode wordt toegepast om energiebesparing/ energieneutraliteit te bereiken?

BREEAM, BREEAM in Use, Energielabels met maatwerk en EPC.

1.5 In hoeverre wordt er energiebesparing gecreëerd ten opzichte van de oude situatie?

12% besparing is realistisch, als het oude gebouwen betreft kan dit percentage oplopen tot maximaal 40%, realistisch gezien 15-20%. Bij oude gebouwen zijn vaak de verlichting en verwarming oud waardoor de besparing vaak hoog is.

2 Aspecten met betrekking tot energiebesparing / energieneutraliteit

2.1 Welke aspecten zijn belangrijk en worden meegenomen bij energiebesparing/ energieneutraliteit?

Als eerste het inzicht in energieverbruik hierbij moet je eerst weten wat het gebouw doet voordat je iets gaat ondernemen. (2) Gebouwoptimalisatie (3) Energiekosten en (4) CO2 emissie. Grid connectie is minder van belang omdat je eerst bij jezelf moet gaan kijken daarna pas wat het grid je kan bieden.

2.2 Waar gaat de voorkeur naar uit met betrekking tot energiebesparing /energieneutraliteit? Duurzame energie op gebouwterrein of duurzame energie buiten gebouwterrein?

Op eigen terrein, aangezien je alles kunt toekennen aan het gebouw, maar is vaak onvoldoende.

2.3 Welke elementen worden toegepast om een gebouw te verduurzamen?

Gebouw specificatie optimalisatie, automatiseren binnenklimaat gebouw en duurzame energieopwekking op het gebouwterrein zelf.

2.4 Welke elementen zijn volgens u het meeste van belang om energieneutraliteit te bereiken?

Energiebesparende maatregelen bestaande uit procesapparatuur, verlichting, isolatie, tochtwering en zonwering, verwarming en warmwater, ventilatie en koeling. Daarnaast is de terugverdientijd op dit moment zeer belangrijk of er geïnvesteerd gaat worden ja of nee. M.b.t. kantoren binnen 3 jaar, hebben ze het geld ervoor over. Bij 5-10 jaar wordt het al lastiger, ligt vooral aan de portefeuille van het bedrijf.

3 Onderzoek specifieke vragen

3.1 Aan de hand van de hierboven gegeven definities, welke is in de praktijk het beste toepasbaar? (e.g. metrisch evenwicht, energieneutraliteit aan de hand van klimaat gegevens, periode van energieneutraliteit of on-site en off-site energieneutraliteit)

Op volgorde van best toepasbaarheid: (1) Metrisch evenwicht, (2) periode van energieneutraliteit, (3) on-site en off-site, (4) klimaatgegevens.

3.3 Wat verstaat u onder energieneutraliteit?

Wat een gebouw nodig heeft (e.g. verlichting, verwarming, verkoeling), en niet alle niet-plaats gebonden aspecten zoals printers, computers et cetera. Met behulp van energetische optimalisaties en natuurlijk energieopwekking kan een gebouw energieneutraal worden gemaakt. Daarnaast is het ook belangrijk om de duurzaamheidsbesparingen te tonen (kenbaar maken). Hiervoor is het belangrijk om vanuit een bedrijf te laten zien dat ze voor de deur zonnepanelen hebben liggen, waaruit blijkt dat ze ermee bezig zijn. Dus niet compenseren vanuit een ver land (zonnepanelen in de woestijn)

4 Model specifieke vragen

4.1 Om tot een goede balans te komen moeten ook de standaard gebruiken van de gebruiker veranderd worden. O.a. om een constante temperatuur in het gebouw realiseren en het gebruik van elektriciteit van externe apparaten (printers e.d.), in hoeverre kan Heijmans deze gebruiken beïnvloeden?

Met behulp van huismeesters kan het energieverbruik door de gebruikers beperkt worden. Hierbij gaat iemand specifiek het elektriciteit en gasverbruik van kantoren monitoren. Hierbij moet er zo veel mogelijk ingezet worden op tijdklokken, apparaten uitzetten tijdens vakanties en na kantoor uren.

APPENDIX 5 – REPORT INTERVIEW R. KOOLEN

Verslaglegging zakelijke weergave expertinterview 4

Datum : 18 maart 2015
Tijd : 10:00 – 11:00, 1 uur
Naam expert : R. Koolen
Functie expert : Directeur strategie en innovatie
Bedrijf : Heijmans woningbouw & vastgoed
Interviewer : E. van Oosterhout
Plaats interview : Rosmalen

1 Algemene vragen

1.1 Wordt er op dit moment binnen Heijmans gefocust op energiebesparing en/of energie-neutraliteit binnen bestaande utiliteitsgebouwen?

Energieneutraliteit komt bij enkele projecten voor. Sinds 2005 wordt er al gewerkt met energie neutrale gebouwen voor nieuwbouw. Voor bestaande bouw worden op dit moment concepten voor ontwikkeld maar worden nog niet daadwerkelijk uitgevoerd.

1.2 Is energieneutraliteit ook daadwerkelijk haalbaar volgens u?

Ja op beide mogelijk, in dit geval betekend energieneutraliteit een EPC van 0. Rekening houdend met dat op dit moment is fossiele energie duurder is dan duurzame energie. Waardoor de business case niet sluitend is. Alhoewel er op dit moment bepaalde plekken zijn waarbij duurzame energie al goedkoper is dan fossiele energie.

1.4Welke methode wordt toegepast om energiebesparing/ energieneutraliteit te bereiken?

Er is op dit moment een verandering gaande bij de overheid. Ze willen van EPC over op BENG (bijna energie neutrale gebouwen). Hierdoor zal er een nieuwe methodiek gaan komen voor EPG aangezien deze EPC als basis heeft.

1.5 In hoeverre wordt er energiebesparing gecreëerd ten opzichte van de oude situatie?

Afhankelijk van de situatie. Voor woningbouw wordt dit gedaan door middel van energielabels waarbij van een E label (slecht) naar een A+ label (goed) wordt gegaan. De vraag is echter of je hier ook daadwerkelijk een energiebesparing bereikt.

2 Aspecten met betrekking tot energiebesparing / energieneutraliteit

2.1 Welke aspect ligt ten grondslag bij energiebesparing/ energieneutraliteit?

Vanuit Heijmans is het streven naar een total cost of ownership (voornamelijk woningbouw). Helaas is dit begrip nog niet goed bekend bij de consument. Dit zorgt ervoor dat er niet alleen gekeken wordt naar energiekosten of exploitatiekosten. Dit gebeurt voornamelijk naar gebouw optimalisatie en slimme meters.

2.2 Waar gaat de voorkeur naar uit met betrekking tot energiebesparing /energieneutraliteit? Duurzame energie op gebouwterrein of duurzame energie buiten gebouwterrein?

Vanuit Heijmans gaat de voorkeur uit naar gebiedsniveau, alleen is de wetgeving daar niet op aangepast. Als je een woning wilt ontwerpen waarbij energie opgewerkt wordt vanuit een centrale windmolen die meer mensen gebruiken, mag dit niet. Hierbij stellen de regels dat op gebouwterrein niveau de regels gelden en wordt er niet gekeken naar maatregelen van buitenaf, waardoor windmolens niet meegerekend mogen worden als zijnde maatregel.

2.3 Welke elementen worden toegepast om een gebouw te verduurzamen?

Optimaliseren binnenklimaat, automatiseren binnenklimaat en duurzame energieopwekking op gebouwterrein niveau. Eigenlijk zou een gebouw opgeleverd moeten worden inclusief duurzame stroom.

2.4 Welke elementen zijn volgens u het meeste van belang om energieneutraliteit te bereiken?

Een mix van een goede gebouwschil, installaties en gebiedsoplossingen.

3 Onderzoek specifieke vragen

3.1 Aan de hand van de hierboven gegeven definities, welke is in de praktijk het beste toepasbaar? (e.g. metrisch evenwicht, energieneutraliteit aan de hand van klimaat gegevens, periode van energieneutraliteit of on-site en off-site energieneutraliteit)

Niet een specifieke definitie is het beste toepasbaar. Het is beter om ze in combinatie te gebruiken aan de hand van zowel de exploitatiefase als de CO_2 uitstoot van materialen. Ook zou er gebiedstoerekening mogelijk moeten zijn.

3.3 Wat verstaat u onder energieneutraliteit?

De beste vertaling is een vertaling die iedereen begrijpt en eenvoudig te gebruiken is, maar dit wil niet zeggen dat dit de beste is. Het moet niet gevangen worden in 1 getal, maar er moet gewoon logisch nagedacht blijven worden. Energieneutraliteit is een samentrekking van gebouwomgeving, EPC, gebruikersfase en materiaalgebruik. Dit zou de ideale situatie zijn, de vraag is echter of dit ook praktisch is.

4 Model specifieke vragen

4.1 Om tot een goede balans te komen moeten ook de standaard gebruiken van de gebruiker veranderd worden. O.a. om een constante temperatuur in het gebouw realiseren en het gebruik van elektriciteit van externe apparaten (printers e.d.), in hoeverre kan Heijmans deze gebruiken beïnvloeden?

D.m.v. inzicht in energieverbruik en coaching. Wel belangrijk dat er geen verplichtingen komen voor de gebruiker. Hierdoor beperk je de mensen in hun keuzes en zullen zij de oplossingen weigeren.

Op gebouwniveau is de Ideale combinatie op dit moment een Rc van 5 a 6 en de investeringskosten moeten binnen 5-10 jaar terugverdient zijn. Dit is afhankelijk van installatie en isolatie ontwikkelingen. Balans moet gevonden worden aan de hand van de tijd, ontwikkelingen en innovatie.

APPENDIX 6 – REPORT INTERVIEW H. VAN HAUWE

Verslaglegging zakelijke weergave expertinterview 5

Datum : 12 maart 2015
Tijd : 09:00 – 10:30, 1.5 uur
Naam expert : H. van Hauwe
Functie expert : Adviseur duurzaamheid
Bedrijf : Heijmans utiliteit
Interviewer : E. van Oosterhout
Plaats interview : Rosmalen

1 Algemene vragen

1.1 Wordt er op dit moment binnen Heijmans gefocust op energiebesparing en/of energie-neutraliteit binnen bestaande utiliteitsgebouwen?

De begrippen horen bij elkaar, het is dezelfde methodiek alleen in hoeverre ga je door hangt af van de opdrachtgever. Visie vanuit Heijmans zelf is in 2020 de gebouwen energieneutraal op te leveren. Reeds zijn er al wel energie neutrale gebouwen opgeleverd met als onderlegger een BREEAM label. Daarnaast wordt er ook naar energieprestatie van een gebied gekeken.

1.2 Is energieneutraliteit ook daadwerkelijk haalbaar volgens u?

In bestaande bouw is dat afhankelijk van de omgevingsfactoren, o.a. op wat voor terrein staat het gebouw, staat het in de stad etc. In de stad op gebouwterrein zelf zal energieneutraliteit moeilijk worden. Als er gekeken wordt naar een energieneutraal gebied kan voor een stad de omgeving gebruikt worden waardoor neutraliteit wel mogelijk is.

1.3 Bij welke soort bouw wordt momenteel energiebesparing of energieneutraliteit toegepast?

Zowel nieuwbouw als bestaande bouw. Op dit moment alleen specifiek de gebouwen met een ruim budget en aan de hand van de overheidsambities.

1.4 Welke methode wordt toegepast om energiebesparing/ energieneutraliteit te bereiken?

Voornamelijk BREEAM en GRP op basis van EPC vanuit de overheid aangestuurd. Op dit moment voornamelijk EPG en EMG (energiemaatregelen op gebiedsniveau).

1.5 In hoeverre wordt er energiebesparing gecreëerd ten opzichte van de oude situatie?

Meestal wordt er gevraagd naar een 30% - 40% verbetering t.o.v. de oude situatie. Daarnaast is het ook afhankelijk van het contract. Als er voor Heijmans een onderhoudstermijn bij zit, wordt er efficiënter naar het elektriciteitsverbruik gekeken.

2 Aspecten met betrekking tot energiebesparing / energieneutraliteit

2.1 Welke aspecten zijn belangrijk en worden meegenomen bij energiebesparing/ energieneutraliteit?

Het hoofddoel veranderd steeds meer naar maatschappelijk verantwoord ondernemen waarbij CO_2 emissie wordt steeds minder de hoofddrijfveer is. Daarnaast krijgen bedrijven ook korting als ze goed scoren op de MVO presentatieladder. Hier zit een afgeleid economisch model in. Deze score is echter wel groter dan alleen het gebouw. Maar ook politieke onafhankelijkheid is van belang.

2.2 Waar gaat de voorkeur naar uit met betrekking tot energiebesparing /energieneutraliteit? Duurzame energie op gebouwterrein of duurzame energie buiten gebouwterrein?

Gebaseerd op het concept trias energetica zou je vanuit je gebouw moeten beginnen.

2.3 Welke elementen worden toegepast om een gebouw te verduurzamen?

Bij bestaande bouw is het voornamelijk van belang om naar inzicht in energieverbruik te kijken. Je moet weten wat je verbruikt om te controleren of dit klopt met wat het zou moeten verbruiken. Vervolgens moet je een ambitie vormen hoe laag je wil gaan zitten.

2.4 Welke elementen zijn volgens u het meeste van belang om energieneutraliteit te bereiken?

Bij bestaande bouw is de grootste parameter het energieverbruik door de gebruiker. Inzicht in gebruiker is daarom het belangrijkste om inzicht te vergaren in het elektriciteitsverbruik. Daarnaast moet er ook gekeken worden naar de veroudering van de bouwmaterialen. Verduurzaming heeft ook een houdbaarheidsdatum. Kwaliteitstoetsing van de schil is hierbij ook van belang. Bij 'nul op de meter' is het doel zo min mogelijk energie transporteren via het grid. Nadeel van een grid is o.a. de verdeling van een gezamenlijke windmolen. Je bent meestal verplicht om stroom voor een bepaalde periode af te nemen. Hierdoor loop je het risico dat je de stroom te duur moet inkopen.

3 Onderzoek specifieke vragen

3.1 Aan de hand van de hierboven gegeven definities, welke is in de praktijk het beste toepasbaar? (e.g. metrisch evenwicht, energieneutraliteit aan de hand van klimaat gegevens, periode van energieneutraliteit of on-site en off-site energieneutraliteit)

Energie (gebruikersparameters) en materiaal parameters van je gebouw en het bouwproces komt overeen met metrisch evenwicht (zoals nul op de meter). De definitie aan de hand van klimaat gegevens wordt er op dit moment niet gebruikt. De periode van energie neutraliteit zou wel meer in de praktijk meer gebruikt moeten worden, aangezien materialen ook belangrijk zijn in het gehele proces. Zo is er op dit moment sprake van materiaal schaarste wat ook belangrijk is om mee te nemen. Echter LCC is niet zo zeer energie gestuurd, waardoor LCC niet de juiste methode is in combinatie met energieneutraliteit. In de praktijk is metrisch evenwicht het beste toepasbaar, echter periode van energieneutraliteit zal met de tijd belangrijker worden. On-site en off-site is echter moeilijk te kiezen, meestal is dit een kostenafweging en andere overwegingen zoals geluidshinder. Het is een wankel evenwicht waarbij je op het terrein zelf kunt investeren maar buiten het terrein investeren levert weer minder natuurgebied op. Dit is afhankelijk van de toepassingen (bijv. zonnepanelen of windturbines).

3.3 Wat verstaat u onder energieneutraliteit?

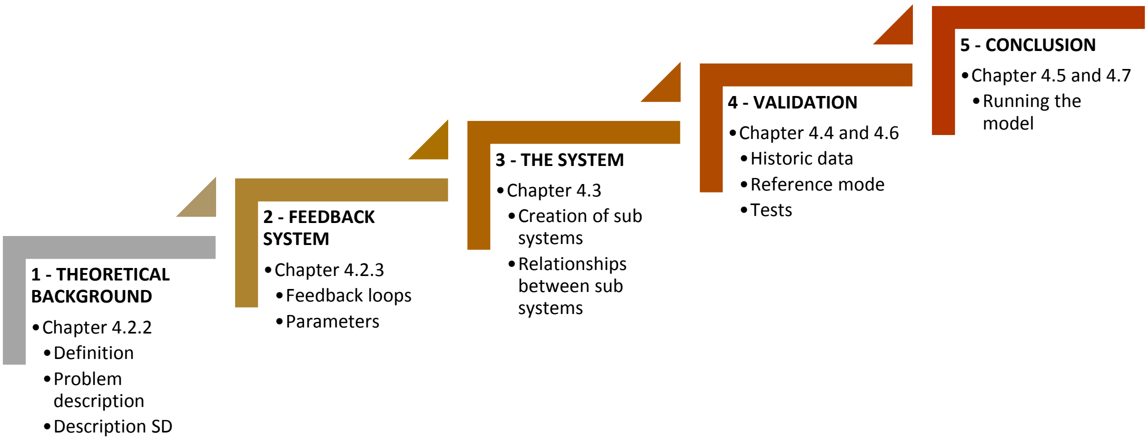
Voor energieneutraliteit moet de EPC gebruikt worden en voor CO_2 neutraal 'nul op de meter' gebruikt worden. Idealiter zou er een combinatie van de twee gebruikt moeten worden.

4 Model specifieke vragen

4.1 Om tot een goede balans te komen moeten ook de standaard gebruiken van de gebruiker veranderd worden. O.a. om een constante temperatuur in het gebouw realiseren en het gebruik van elektriciteit van externe apparaten (printers e.d.), in hoeverre kan Heijmans deze gebruiken beïnvloeden?

Door middel van het regelen van de gebruiker. Als er maar 10 mensen werken, zet deze in 1 kamer en sluit de rest van het pand waardoor geen energie verspilt wordt. Kortom inspelen op het aantal mensen dat er die dag aanwezig zal zijn. Door middel van informeren zullen de gebruikers dit wel accepteren. Daarnaast is er een grens waarop de systemen geoptimaliseerd moeten worden, de grens volgens de norm is lager maar dit kan wel resulteren in het verlagen van productiviteit. Hierin is energiekosten van ondergeschikt belang, dit gaat echter in tegen energiezuinig. Het doel is om de lijn van het totale verbruik (o.a. warmte en koeling) steeds vlakker te krijgen i.p.v. een normaal curve moet er een zo vlak mogelijke lijn komen. De reden hiervoor is dat het op dit moment er lastig is om energieopslag toe te passen. Als er gekeken wordt duurzame technologieën zijn windturbines (Heijmans Airwiss) minder makkelijker toepasbaar dan zonnepanelen. Daarnaast zorgt een windturbine voor veel extra beperkingen en regels e.g. aanvraag vergunning, geluidsoverlast, constructie dak etc.

APPENDIX 7 – STEPS IN SYSTEM DYNAMICS



Step 1 theoretical background – in the first step of the research, the definition of the problem and the method are given. The basic principles which are the foundation of System Dynamics (SD) are reviewed in order to create a framework for the rest of the research, explained in chapter 4.2.2.

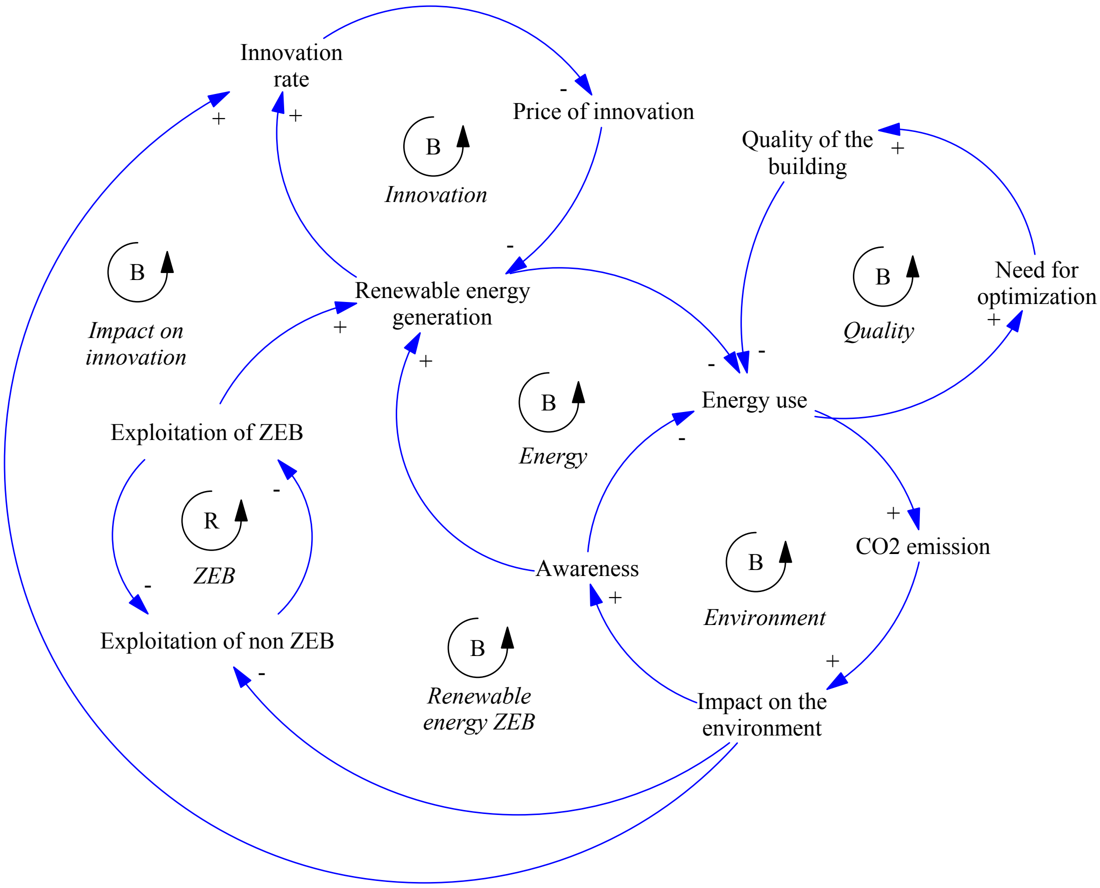
Step 2 feedback system – the feedback system is created in order to describe relevant feedback loops. These feedback loops are the foundation of the SD model. In the loops, the parameters that influence each other are given. A causal loop diagram contains a number of variables, which are connected by arrows with a causal relationship (causal chain). Which exists of either a positive (+) or negative causal relationship (-). It is an important tool to show the feedback structure of the system (Ventana Systems, inc., 1989-2012). This step is explained in chapter 4.2.3.

Step 3 the system – in this step, the SD model is created with the software package Vensim. This is done by creating subsystems that are founded on one of the feedback loops as created in step [2]. The stock and flow diagram is a further description of the system based on the causal relationship explained in the causal loop. It reflects the logical relationship among the system elements clearly and clearly shows the cumulative effects and rate of change of each variable (Ventana Systems, inc., 1989-2012). This step is explained in chapter 4.3.

Step 4 validation – validation of the (sub) model(s) is mostly done by using one of two options: using historic data to see if the model follows the patterns that occurred in the past or by using a case study in order to find out if the system is correct for a specific situation. In this research the validation is done with a case study and historic data (e.g. experts and a report). This step is explained in chapter 4.4 and 4.6.

Step 5 conclusion – when the model is validated, the model can start simulating the information and the results from this will be used to generate conclusions and advice on the best possible ways of action in order to influence the system and solve the problem. This step is explained in chapter 4.5 and 4.7.

APPENDIX 8 – EXPLAINATION OF THE CAUSEL LOOP



Innovation loop – the innovation loop identifies when the people are willing to innovate for renewable energy generation. The more renewable energy generation that is needed, the higher the innovation rate will be. And when there is much choice due to the innovation the overall price of the innovation will be lower and with that, the price of renewable energy will be lower and people will go for renewable energy generation. But due to low prices and the availability of renewable energy, the innovation will stop. Together this process can be described as a balancing loop.

Quality loop – the energy use of a building is depended on the quality of the building. If the quality of the building is low (due to age, old systems etcetera) more energy is needed. If people have to use too much energy they will think about the optimization (e.g. systems, insulation etc.) of the building to reduce the energy use. If the optimization is done, the quality of the building will be high again and people will use less energy. This process can be again described as a balancing loop.

Environmental loop – the environmental loop can be described as when people will start lowering their fossil energy use. The more fossil energy use that is used, the more CO_2 emission is produced. The more CO_2 emission the more (bad) impact it has on the environment (e.g. global warming). The more people that are aware of the fact of global warming, the more awareness there is to prevent global warming. The awareness has the effect of using less fossil energy. This loop can be described as a balancing loop. Awareness has other effects such as awareness of renewable energy, this will be discussed next in the energy loop.

Energy loop – the energy loop includes the environment loop. When there is awareness to reduce the fossil energy use, the awareness for renewable energy generation will grow. The effect of generation of renewable energy on the overall fossil energy use is the lowering of the energy use. The other way is also true, if people are not aware of the impact of using fossil energy people will not go for renewable energy generation and the fossil energy use will not be lower. This loop can be described as a balancing loop.

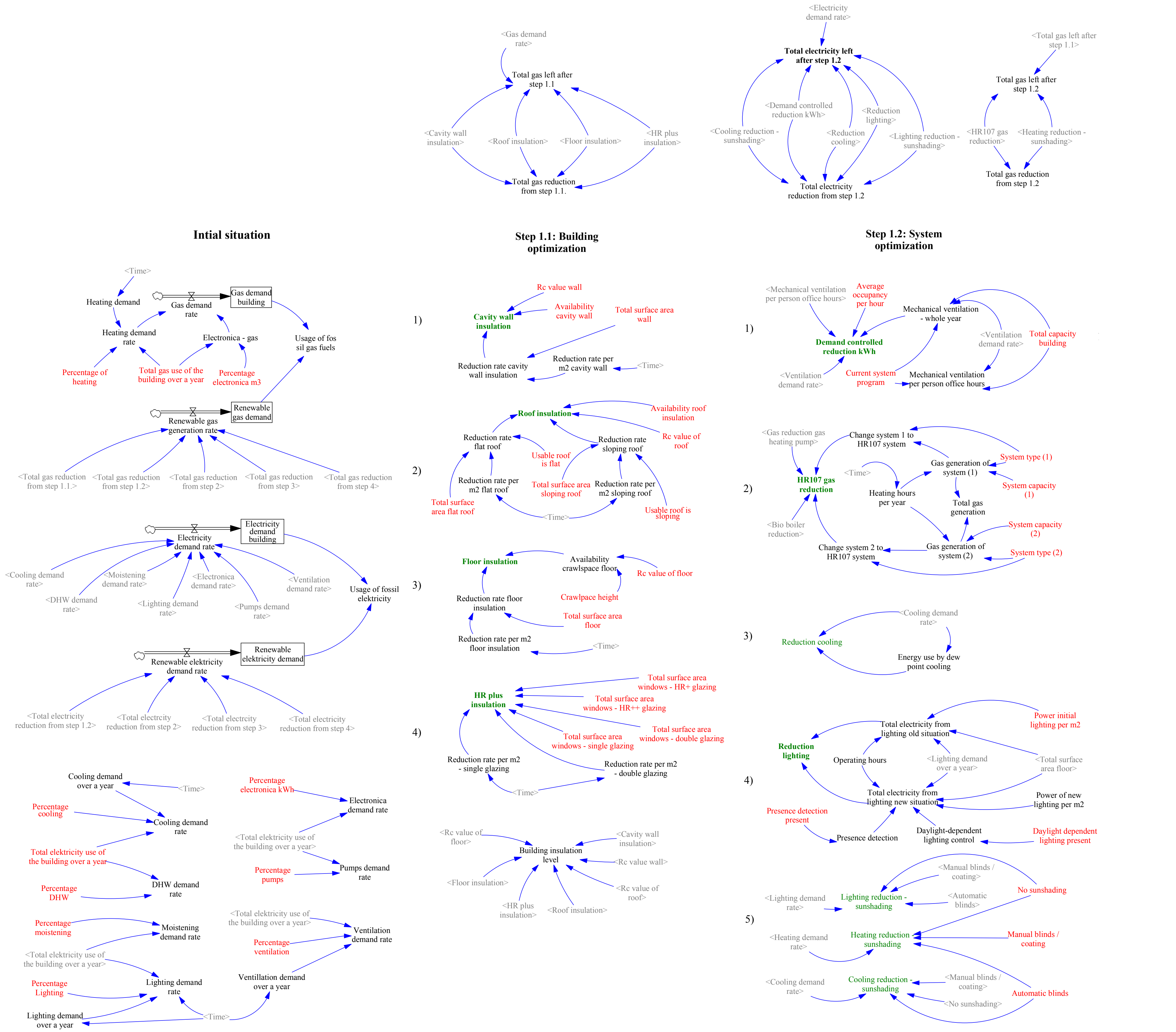
ZEB loop – the ZEB loop can be described as when people are willing to invest in energy neutral buildings, they will not invest in non-energy neutral buildings, the opposite is also true, which means that they reinforce each other. This loop can be combined with the renewable energy ZEB loop which combines the environmental loop and the energy loop.

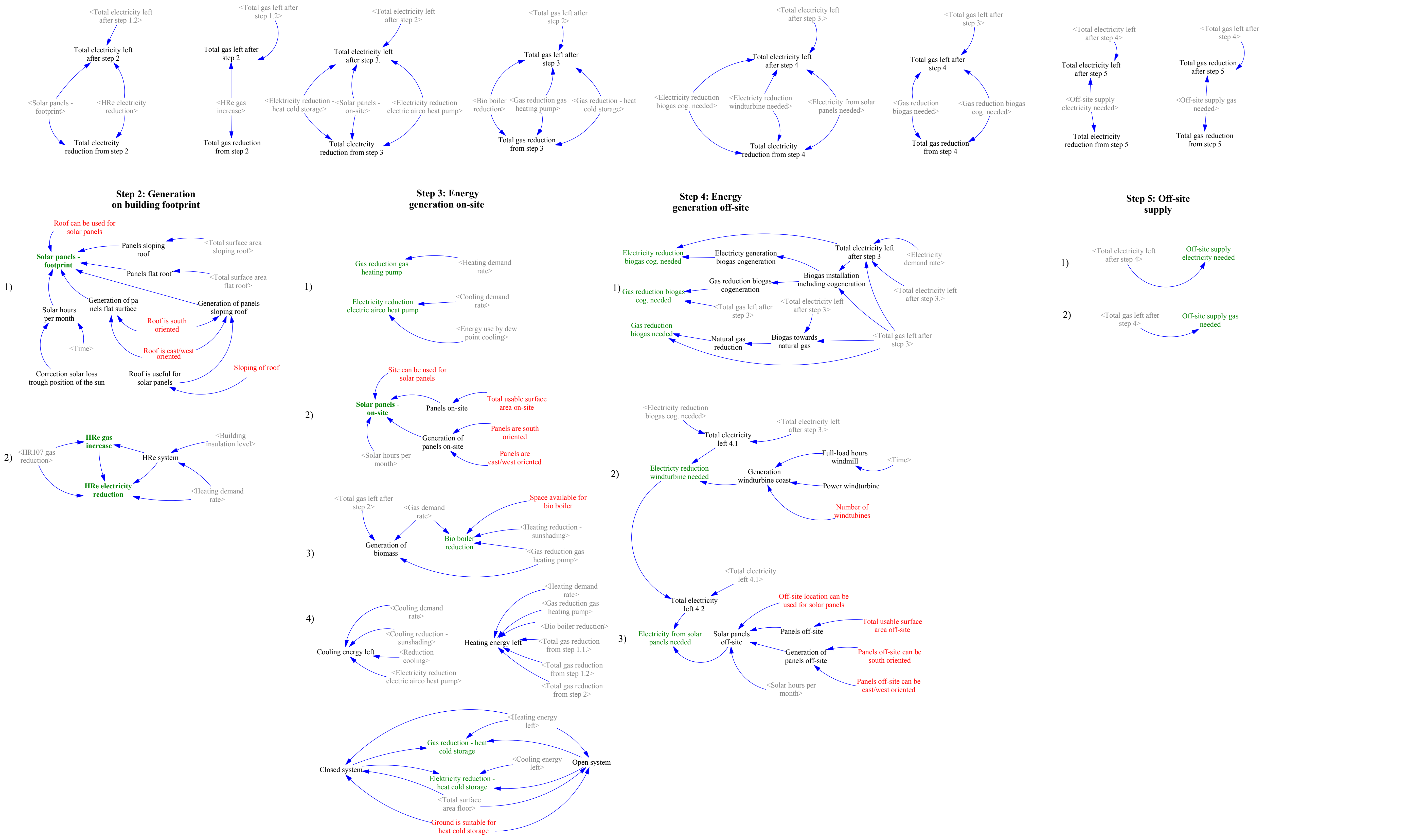
Renewable energy ZEB loop – the renewable energy loop describes the effect what the environmental impact has on the energy use and the exploitation of ZEB. If the impact from fossil fuels is high on the environment the people will invest more in ZEB buildings instead of non ZEB buildings. Because of this effect, people will start looking for renewable energy generation which lowers the fossil energy use. Together, these loops form a balancing loop.

Impact on innovation loop – the last loop combines the environment loop, energy loop and the innovation loop. If the impact of fossil energy use on the environment is high, the innovation of renewable energy will grow. The opposite is also true, if the impact of fossil fuels is low on the environment (due to renewable energy generation) the innovation for renewable energy generation will lower. Together this makes a balancing loop.

APPENDIX 9 – VENSIM MODEL ON THE NEXT PAGE

APPENDIX 9 – VENSIM MODEL





<Total electricity left after step 1.2>
Total electricity left after step 2
<Solar panels - footprint>
<HRe electricity reduction>
Total electrcity reduction from step 2
<Total gas left after step 1.2>
Total gas left after step 2
<HRe gas increase>
Total gas reduction from step 2
<Total electricity left after step 2>
Total electricity left after step 3.
<Elektricity reduction - heat cold storage>
<Solar panels - on-site>
<Electricity reduction electric airco heat pump>
Total electrcity reduction from step 3
<Total gas left after step 2>
Total gas left after step 3
<Bio boiler reduction>
<Gas reduction gas heating pump>
<Gas reduction - heat cold storage>
Total gas reduction from step 3
<Total electricity left after step 3.>
Total electricity left after step 4
<Electricity reduction biogas cog. needed>
<Electricity reduction windturbine needed>
<Electricity from solar panels needed>
Total electricity reduction from step 4
<Total gas left after step 3>
Total gas left after step 4
<Gas reduction biogas needed>
<Gas reduction biogas cog. needed>
Total gas reduction from step 4
<Total electricity left after step 4>
Total electricity left after step 5
<Off-site supply electricity needed>
Total electricity reduction from step 5
<Total gas left after step 4>
Total gas reduction after step 5
<Off-site supply gas needed>
Total gas reduction from step 5
Step 2: Generation on building footprint
1)
Roof can be used for solar panels
Solar panels - footprint
Panels sloping roof
<Total surface area sloping roof>
Panels flat roof
<Total surface area flat roof>
Generation of panels flat surface
Generation of panels sloping roof
Solar hours per month
Roof is south oriented
Roof is east/west oriented
<Time>
Sloping of roof
Correction solar loss trough position of the sun
Roof is useful for solar panels
2)
HRe gas increase
<HR107 gas reduction>
HRe system
<Building insulation level>
HRe electricity reduction
<Heating demand rate>
Step 3: Energy generation on-site
1)
Gas reduction gas heating pump
<Heating demand rate>
Electricity reduction electric airco heat pump
<Cooling demand rate>
<Energy use by dew point cooling>
2)
Site can be used for solar panels
Solar panels - on-site
Panels on-site
Total usable surface area on-site
Generation of panels on-site
Panels are south oriented
Panels are east/west oriented
<Solar hours per month>
3)
<Total gas left after step 2>
<Gas demand rate>
Space available for bio boiler
Generation of biomass
Bio boiler reduction
<Heating reduction - sunshading>
<Gas reduction gas heating pump>
4)
<Cooling demand rate>
<Cooling reduction - sunshading>
<Reduction cooling>
<Electricity reduction electric airco heat pump>
Cooling energy left
<Heating demand rate>
<Gas reduction gas heating pump>
<Bio boiler reduction>
<Total gas reduction from step 1.1>
<Total gas reduction from step 1.2>
<Total gas reduction from step 2>
Heating energy left
<Heating energy left>
Gas reduction - heat cold storage
Closed system
Open system
<Cooling energy left>
Elektricity reduction - heat cold storage
<Total surface area floor>
Ground is suitable for heat cold storage
Step 4: Energy generation off-site
1)
Electricity reduction biogas cog. needed
Electricty generation biogas cogeneration
Total electricity left after step 3
<Electricity demand rate>
Gas reduction biogas cogeneration
Biogas installation including cogeneration
Gas reduction biogas cog. needed
<Total gas left after step 3>
<Total electricity left after step 3>
<Total electricity left after step 3.>
Gas reduction biogas needed
Natural gas reduction
Biogas towards natural gas
<Total gas left after step 3>
2)
<Electricity reduction biogas cog. needed>
Total electricity left 4.1
<Total electricity left after step 3.>
Electricty reduction windturbine needed
Generation windturbine coast
Full-load hours windmill
<Time>
Power windturbine
Number of windtubines
3)
<Total electricity left 4.1>
Total electricity left 4.2
Off-site location can be used for solar panels
Electricity from solar panels needed
Solar panels off-site
Panels off-site
Total usable surface area off-site
Generation of panels off-site
Panels off-site can be south oriented
Panels off-site can be east/west oriented
<Solar hours per month>
Step 5: Off-site supply
1)
<Total electricity left after step 4>
Off-site supply electricity needed
2)
<Total gas left after step 4>
Off-site supply gas needed

APPENDIX 10 – FORMULAS VENSIM MODEL

00 initial situation			
NAME	EQUATION	UNIT	TYPE
Heating demand	Lookup: ([(0,0)-(11,0.2)], (0,0.188), (0,0.188), (1,0.17), (2,0.151), (3,0.095), (4,0.05), (5,0.021), (6,0.003), (7,0.006), (8,0.034), (9,0.058), (10,0.101), (11,0.123)), equation: time	Percentage	Auxiliary
Heating demand rate	Heating demand*(Percentage of heating*Total gas use of the building over a year)	m3/ month	Auxiliary
Electronica - gas	Electricity demand rate*Percentage electronica m3	m3/month	Auxiliary
Gas demand rate	Heating demand rate+ Electronica - gas	m3/month	Auxiliary
Gas demand building	Gas demand rate, initial value = 0	m3	Level
Renewable gas generation rate	(Total gas reduction from step 1.1. + Total gas reduction from step 1.2 +Total gas reduction from step 2+Total gas reduction from step 3+Total gas reduction from step 4)	m3/month	Auxiliary
Renewable gas demand	Renewable gas generation rate, initial value = 0	m3	Level
Usage of fossil gas fuels	MAX((Gas demand building-Renewable gas demand),0)	m3	Auxiliary
Electricity demand rate	Cooling demand rate+ DHW demand rate+ Electronica demand rate+ Lighting demand rate+ Moistening demand rate+ Pumps demand rate+ Ventilation demand rate	kWh/ Month	Auxiliary
Electricity demand building	Electricity demand rate	kWh	Level
Renewable electricity demand rate	Total electricity reduction from step 1.2 +Total electricity reduction from step 2+Total electricity reduction from step 3+Total electricity reduction from step 4	kWh/ Month	Auxiliary
Renewable electricity demand	Renewable electricity demand rate	kWh	Level
Usage of fossil electricity	MAX(Electricity demand building-Renewable electricity demand, 0)	kWh	Auxiliary
01 Building optimization			
Cavity wall insulation	IF THEN ELSE(Rc value wall<4, (IF THEN ELSE(Availability cavity wall=1,Reduction rate cavity wall insulation, 0)) , 0)	m3/Month	Auxiliary

Reduction rate cavity wall insulation	Total surface area wall*Reduction rate per m2 cavity wall	m3/Month	Auxiliary
Reduction rate per m2 cavity wall	Lookup (Time), initial value ([(0,0.4)-(12,0.9)] ,(0,0.8) ,(1,0.8) ,(2,0.77) ,(3,0.57) ,(4,0.49) ,(5,0.53) ,(6,0.73) ,(7,0.87) ,(8,0.7) ,(9,0.63) ,(10,0.5) ,(11,0.57), (12,0.83))	m3/Month/ m2	Auxiliary
Roof insulation	IF THEN ELSE(Rc value of roof<4,IF THEN ELSE(Availability roof insulation=1,Reduction rate flat roof+ Reduction rate sloping roof, 0), 0)	m3/Month	Auxiliary
Reduction rate flat roof	IF THEN ELSE(Usable roof is flat=1,Reduction rate per m2 flat roof,0)*Total surface area flat roof	m3/Month	Auxiliary
Reduction rate sloping roof	IF THEN ELSE(Usable roof is sloping=1,Reduction rate per m2 sloping roof,0)*Total surface area sloping roof	m3/Month	Auxiliary
Reduction rate per m2 flat roof	Lookup (Time), initial value ([(0,0.6)-(12,2)], (0,1), (1,1), (2,0.96), (3,0.71), (4,0.61), (5,0.67), (6,0.92), (7,1.08), (8,0.88), (9,0.79), (10,0.63), (11,0.71) ,(12,1.04))	m3/Month/ m2	Auxiliary
Reduction rate per m2 sloping roof	Lookup (Time), initial value ([(0,0.5)-(12,1)], (0,0.9), (1,0.9), (2,0.86), (3,0.64), (4,0.55), (5,0.6), (6,0.83), (7,0.98), (8,0.79), (9,0.71) , (10,0.56), (11,0.64), (12,0.94))	m3/Month/ m2	Auxiliary
Floor insulation	IF THEN ELSE(Availability crawlspace floor=1,Reduction rate floor insulation,0)	m3/Month	Auxiliary
Reduction rate floor insulation	Total surface area floor*Reduction rate per m2 floor insulation	m3/Month	Auxiliary
Reduction rate per m2 floor insulation	Lookup (Time), initial value ([(0,0.3)-(12,0.6)], (0,0.52), (1,0.52), (2,0.5), (3,0.45), (4,0.39), (5,0.43), (6,0.48), (7,0.57), (8,0.45), (9,0.5), (10,0.4), (11,0.45), (12,0.55))	m3/Month/ m2	Auxiliary
Availability crawlspace floor	IF THEN ELSE(Rc value of floor<4,IF THEN ELSE (Crawlspace height>35, 1, 0), 0)	-	Auxiliary
HR plus insulation	(Reduction rate per m2 - double glazing * Total surface area windows - double glazing)+ (Reduction rate per m2 - single glazing * Total surface area windows - single glazing)+ (Total surface area windows - HR++ glazing *0)+ (Total surface area windows - HR+ glazing *0)	m3/Month	Auxiliary
Reduction rate per m2 - single glazing	Lookup (Time), initial value ([(0,1)-(12,3)], (0,2.08), (1,2.08), (2,1.99), (3,1.47),(4,1.26), (5,1.38), (6,1.9), (7,2.25), (8,1.82), (9,1.64) , (10,1.3), (11,1.47), (12,2.16))	m3/Month/ m2	Auxiliary

Reduction rate per m2 - double glazing	Lookup (Time), initial value ([(0,0.2)-(12,0.5)], (0,0.45), (1,0.45), (2,0.43), (3,0.32), (4,0.27), (5,0.3), (6,0.41), (7,0.49), (8,0.39), (9,0.36), (10,0.28), (11,0.32), (12,0.47))	m3/month/ m2	Auxiliary
Building insulation level	IF THEN ELSE(Rc value wall=1:OR:Cavity wall insulation>1, 1, IF THEN ELSE(Rc value of roof=1:OR:Roof insulation>1, 1, IF THEN ELSE(Rc value of floor=1:OR:Floor insulation>1, 1, IF THEN ELSE(HR plus insulation>1, 1, 0))))	-	Auxiliary
01 System optimization			
Demand controlled reduction kWh	(Ventilation demand rate)-(Mechanical ventilation per person office hours*Average occupancy per hour*208.3)-(Mechanical ventilation - whole year *Average occupancy per hour*208.3)	kWh/ month	Auxiliary
Mechanical ventilation – whole year	IF THEN ELSE(Current system program=0, (Ventilation demand rate/Total capacity building),0)	kWh/ month	Auxiliary
Mechanical ventilation per person office hours	IF THEN ELSE(Current system program=1, (Ventilation demand rate/Total capacity building/(2500/12)) , 0)	kWh/ month	Auxiliary
HR107 gas reduction	IF THEN ELSE((Change system 1 to HR107 system + Change system 2 to HR107 system)<Gas reduction gas heating pump, 0 , Change system 1 to HR107 system +Change system 2 to HR107 system)	m3/month	Auxiliary
Change system 1 to HR107 system	IF THEN ELSE(System type (1) =1, (Gas generation of system (1) *0.4267) ,IF THEN ELSE(System type (1) =2, (Gas generation of system (1) *0.3375) , IF THEN ELSE(System type (1) =3, (Gas generation of system (1) *0) ,0)))	m3/month	Auxiliary
Change system 2 to HR107 system	IF THEN ELSE(System type (2) =1, (Gas generation of system (2) *0.4267) ,IF THEN ELSE(System type (2) =2, (Gas generation of system (2) *0.3375) , IF THEN ELSE(System type (2) =3, (Gas generation of system (2) *0) ,0)))	m3/month	Auxiliary
Heating hours per year	Lookup, with initial value = time, ([(0,0)-(12,600)], (0,504), (1,504), (2,504),(3,504) ,(3.52294,418.421) ,(4.58716,78.9474) ,(5.76147,26.3158) ,(6.45872,10.5263) ,(7.48624,13.1579) ,(8.40367,21.0526) ,(8.91743,60.5263) ,(10.2752,460.526) , (11,504) ,(12,504))	Hours/ Month	Auxiliary

Gas generation of system (1)	IF THEN ELSE(System type (1) =1, ((System capacity (1) /((0.75*31650)/3600))*Heating hours per year), IF THEN ELSE(System type (1) =2, ((System capacity (1) / ((0.83*31650) / 3600)) * Heating hours per year), IF THEN ELSE(System type (1) =3, ((System capacity (1) / ((1.07 * 31650) / 3600)) *Heating hours per year),IF THEN ELSE(System type (1) =4, ((System capacity (1) / ((1.4*31650)/3600))* Heating hours per year),0)))), initial value =0	m3/month	Auxiliary
Gas generation of system (2)	IF THEN ELSE(System type (2) =1, ((System capacity (2) /((0.75*31650)/3600))*Heating hours per year), IF THEN ELSE(System type (2) =2, ((System capacity (2) / ((0.83 * 31650) / 3600)) *Heating hours per year), IF THEN ELSE(System type (2) =3, ((System capacity (2) / ((1.07 * 31650) / 3600)) *Heating hours per year), IF THEN ELSE (System type (2) =4, ((System capacity (2) / ((1.4*31650) /3600)) *Heating hours per year),0)))), initial value =0	m3/month	Auxiliary
Total gas generation	Gas generation of system (1) + Gas generation of system (2) , initial value =0	m3/month	Level
Reduction cooling	MAX(Cooling demand rate-Energy use by dew point cooling, 0)	kWh/ Month	Auxiliary
Energy use by dew point cooling	Cooling demand rate*0.055	kWh/ Month	Auxiliary
Reduction lighting	Total electricity from lighting old situation-Total electricity from lighting new situation	kWh/ month	Auxiliary
Total electricity from lighting old situation	Total surface area floor*Power initial lighting per m2*Operating hours	kWh/ Month	Auxiliary
Operating hours	2400	Hours/ Month	Auxiliary
Total electricity from lighting new situation	((Power of new lighting per m2*Total surface area floor)*Operating hours)-Presence detection- Daylight-dependent lighting control	kWh/ Month	Auxiliary
Daylight-dependent lighting control	IF THEN ELSE(Presence detection present=1,0,0.3)	-	Auxiliary
Presence detection	IF THEN ELSE(Daylight dependent lighting present=1, 0, 0.3)	-	Auxiliary
Power of new lighting per m2	0.003	kW/m2	Auxiliary

Lighting reduction - sun shading	IF THEN ELSE(No sun shading=1, -Lighting*0.375 , IF THEN ELSE(Manual blinds / coating =1, Lighting *0.312 , IF THEN ELSE(Automatic blinds=1, Lighting *0 , 0)))	kWh/ Month	Auxiliary
Heating reduction - sun shading	IF THEN ELSE(No sun shading=1, -Heating*0.375 , IF THEN ELSE(Manual blinds / coating =1, Heating *0.083 , IF THEN ELSE(Automatic blinds=1, Heating *0 , 0)))	m3/month	Auxiliary
Cooling reduction - sun shading	IF THEN ELSE(No sun shading=1, Cooling*0.6 , IF THEN ELSE(Manual blinds / coating =1, -Cooling *0.312 , IF THEN ELSE(Automatic blinds=1, Cooling *0 , 0)))	kWh/ Month	Auxiliary
02 Generation on building footprint			
Solar panels - footprint	IF THEN ELSE(Roof can be used for solar panels=1, (Solar hours per month*Generation of panels flat surface *Panels flat roof)+(Solar hours per month *Generation of panels sloping roof * Panels sloping roof), 0)	kWh/ month	Auxiliary
Solar hours per month	Time*Correction solar loss trough position of the sun, with Look-up: ([(0,0)-(12,200)], (0,16), (1,20.01), (2,35.78), (3,92.66), (4,118.67), (5,140.84), (6,165.68), (7,156.21), (8,124.55) ,(9,96.02) ,(10,48.05) ,(11,27.06) ,(12,15.19))	Solar hours / month	Auxiliary
Correction solar loss trough position of the sun	0.85	-	Auxiliary
Panels sloping roof	Total surface area sloping roof/1.5	panel	Auxiliary
Panels flat roof	Total surface area flat surface/2.5	panel	Auxiliary
Generation of panels flat surface	IF THEN ELSE(Roof is south oriented=1,0.85*Roof is useful for solar panels, IF THEN ELSE(Roof is east/west oriented =1,0.72*Roof is useful for solar panels,0))	percentage	Auxiliary
Generation of panels sloping surface	IF THEN ELSE(Roof is south oriented=1, 0.8*Roof is useful for solar panels, IF THEN ELSE(Roof is east/west oriented =1,0.68*Roof is useful for solar panels ,0))	percentage	Auxiliary
Roof is useful for solar panels	IF THEN ELSE(Sloping of roof<20,0,IF THEN ELSE(Sloping of roof>60,0,IF THEN ELSE(Sloping of roof>20,1, IF THEN ELSE(Sloping of roof=0,1,1))))	-	Auxiliary
HRe gas increase	-IF THEN ELSE(HRe system=1,HR107 gas reduction*0.13, 0)	m3/month	Auxiliary

Hre electricity reduction	IF THEN ELSE(HRe system=1, ((-HRe gas increase)+(Gas demand building-HR107 gas reduction + HRe gas increase))*13.14,0)	kWh/ Month	Auxiliary
HRe system	IF THEN ELSE(Building insulation level=0:AND:Gas demand building>2000, 1, 0)	-	Auxiliary
03 Energy generation on-site			
Gas reduction gas heating pump	Heating demand rate/((3.4)-0.7)	m3/month	Auxiliary
Electricity reduction electric airco heating pump	(IF THEN ELSE((Cooling demand rate-Energy use by dew point cooling)<(Cooling demand rate/(3-0.7)), Cooling demand rate/(3-0.7), 0))	kWh/ month	Auxiliary
Solar panels - on-site	IF THEN ELSE(Site can be used for solar panels=1, Panels on-site *Solar hours per month * Generation of panels on-site , 0)	kWh/ Month	Auxiliary
Panels on-site	Total usable surface area on-site /2.5	Panels	Auxiliary
Generation of panels on-site	IF THEN ELSE(Panels are south oriented=1,0.85,IF THEN ELSE(Panels are east/ west oriented =1,0.72,0))	percentage	Auxiliary
Bio boiler reduction	(IF THEN ELSE(Space available for bio boiler=1, Heating demand rate- Heating reduction – sun shading -Gas reduction gas heating pump, 0))	m3/month	Auxiliary
Generation of biomass	((Heating demand rate-Total gas left after step 2-Gas reduction gas heating pump) /363.1) + (((Heating demand rate-Total gas left after step 2-Gas reduction gas heating pump)/363.1)*0.1)	ton/month	Auxiliary
Gas reduction - heat cold storage	MAX((IF THEN ELSE(Closed system=1:AND:Open system=0, (Open system*Heating energy left)*0.4, (Open system*Heating energy left)*0.5)), 0)	m3/month	Auxiliary
Electricity reduction - heat cold storage	(IF THEN ELSE(Closed system=0:AND:Open system=1, (Open system*Cooling energy left)*0.8 , (Open system*Cooling energy left)*0.7))	kWh/ month	Auxiliary
Closed system	IF THEN ELSE(Heating energy left=0, 0 , IF THEN ELSE(Total surface area floor<10000:AND:Ground is suitable for heat cold storage=1, 1 ,0))	-	Auxiliary
Open system	IF THEN ELSE(Heating energy left=0, 0 ,IF THEN ELSE(Total surface area floor>10000:AND:Ground is suitable for heat cold storage=1, 1 ,0))	-	Auxiliary
Cooling energy left	MAX(Cooling-Electricity reduction electric airco heat pump-Reduction cooling- Cooling reduction - sun shading ,0)	kWh/ Month	Auxiliary

Heating energy left	MAX(Heating-Bio boiler reduction-Gas reduction gas heating pump-HR107 gas reduction-(-HRe gas increase)- Total gas reduction after step 1.1 - Heating reduction - sun shading , 0)	m3/month	Auxiliary
04 Energy generation off-site			
Electricity reduction biogas cog. needed	Electricity generation biogas cogeneration-(Electricity generation biogas cogeneration-Total electricity left after step 3)	kWh/ Month	Auxiliary
Gas reduction biogas cog. needed	Gas reduction biogas cogeneration-(Gas reduction biogas cogeneration-Total gas left after step 3)	m3/month	Auxiliary
Gas reduction biogas needed	Natural gas reduction-(Natural gas reduction-Total gas left after step 3)	m3/month	Auxiliary
Electricity generation biogas cog.	Biogas installation including cogeneration*4	kWh/ Month	Auxiliary
Gas reduction biogas cog.	(Biogas installation including cogeneration*2)/9.769	m3/month	Auxiliary
Biogas installation including cog.	IF THEN ELSE(Total gas left after step 3>0:AND:Total electricity left after step 3>0,150000,0)	m3/month	Auxiliary
Total electricity left after step 3	IF THEN ELSE(Total gas left after step 3>0, Electricity demand rate- Total electricity left after step 3. , 0)	kWh/ Month	Auxiliary
Natural gas reduction	((Biogas towards natural gas*0.74))	m3/month	Auxiliary
Biogas towards natural gas	IF THEN ELSE(Total electricity left after step 3<0:AND:Total gas left after step 3>0, 150000, 0)	m3	Auxiliary
Electricity reduction wind turbine needed	IF THEN ELSE(Total electricity left 4.1 >0, (Generation wind turbine coast-(MAX((Generation wind turbine coast- Total electricity left 4.1), 0))) , 0)	kWh/ Month	Auxiliary
Generation wind turbine coast	Full-load hours windmill *Power wind turbine	kWh/ Month	Auxiliary
Full-load hours windmill	Lookup (Time) with initial value ([(0,0)-(12,400)], (0,287), (1,330), (1,330), (2,335), (3,147), (4,115), (5,221), (6,81), (7,106), (8,106), (9,68), (10,227), (11,173), (12,287), (12,287) ,(12.01,0))	hours/ Month	Auxiliary
Power wind turbine	1000	kWh	Auxiliary
Total electricity left 4.1	Total electricity left after step 3. - Electricity reduction biogas cog. needed	kWh	Auxiliary

Electricity from solar panels needed	IF THEN ELSE(Total electricity left 4.2 >0, (Solar panels off-site -(MAX((Solar panels off-site - Total electricity left 4.2), 0))) , 0)	kWh/ Month	Auxiliary
Solar panels off-site	IF THEN ELSE(Off-site location can be used for solar panels =1, Panels off-site *Solar hours per month* Generation of panels off-site , 0)	kWh/ Month	Auxiliary
Panels off-site	Total usable surface area off-site /2.5	Panels	Auxiliary
Generation off-site	IF THEN ELSE(Panels off-site can be south oriented =1,0.85,IF THEN ELSE(Panels off-site can be east/west oriented =1,0.72,0))	Percentage	Auxiliary
Total electricity left 4.2	Total electricity left 4.1 - Electricity reduction wind turbine needed	kWh/ Month	Auxiliary
05 Off-site supply			
Off-site supply electricity needed	Total electricity left after step 4	kWh/ Month	Auxiliary
Off-site supply gas needed	Total gas left after step 4	m3/month	Auxiliary
General information			
Total gas reduction left after step 1.1	MAX(Gas demand rate-(Cavity wall insulation + Floor insulation + HR plus insulation + Roof insulation) , 0)	m3/month	Auxiliary
Total gas reduction from step 1.1	Cavity wall insulation + Floor insulation + HR plus insulation + Roof insulation	m3/month	Auxiliary
Total gas reduction left after step 1.2	Gas demand rate-(Gas demand rate- Total gas reduction after step 1.1)-HR107 gas reduction-Heating reduction - sun shading	m3/month	Auxiliary
Total gas reduction from step 1.2	HR107 gas reduction + Heating reduction - sun shading	m3/month	Auxiliary
Total electricity reduction left after step 1.2	MAX(Electricity demand rate-(Reduction lighting + Reduction cooling + Demand controlled reduction kWh + Cooling reduction - sun shading + Lighting reduction - sun shading) , 0)	kWh/ Month	Auxiliary
Total electricity reduction from step 1.2	Demand controlled reduction kWh + Reduction cooling + Reduction lighting + Cooling reduction - sun shading + Lighting reduction - sun shading	kWh/ Month	Auxiliary
Total gas reduction left after step 2	MAX((Gas demand rate-(Gas demand rate-Total gas reduction after step 1.2)+HRe gas increase) , 0)	m3/month	Auxiliary
Total gas reduction from step 2	HRe gas increase	m3/month	Auxiliary

Total electricity reduction left after step 2	MAX(Electricity demand rate-(Electricity demand rate- Total electricity reduction after step 1.2)- Solar panels - footprint -HRe electricity reduction, 0)	kWh/ Month	Auxiliary
Total electricity reduction from step 2	HRe electricity reduction + Solar panels - footprint	kWh/ Month	Auxiliary
Total gas reduction left after step 3	MAX((Total gas left after step 2-Gas reduction gas heating pump- Gas reduction - heat cold storage -Bio boiler reduction), 0)	m3/month	Auxiliary
Total gas reduction from step 3	Gas reduction gas heating pump+ Bio boiler reduction + Gas reduction - heat cold storage	m3/month	Auxiliary
Total electricity reduction left after step 3	MAX((Total electricity left after step 2- Solar panels - on-site -Electricity reduction electric airco heat pump- Electricity reduction - heat cold storage), 0)	kWh/ Month	Auxiliary
Total electricity reduction from step 3	Electricity reduction electric airco heat pump+ Solar panels - on-site + Electricity reduction - heat cold storage	kWh/ Month	Auxiliary
Total gas reduction left after step 4	MAX((Total gas left after step 3)- Gas reduction biogas cog. needed -Gas reduction biogas needed, 0)	m3/month	Auxiliary
Total gas reduction from step 4	Gas reduction biogas cog. needed + Gas reduction biogas needed	m3/month	Auxiliary
Total electricity reduction left after step 4	MAX ((Total electricity left after step 3. -Electricity from solar panels needed - Electricity reduction biogas cog. needed -Electricity reduction wind turbine needed), 0)	kWh/ Month	Auxiliary
Total electricity reduction from step 4	Electricity reduction biogas cog. needed + Electricity reduction wind turbine needed +Electricity from solar panels needed	kWh/ Month	Auxiliary
Total gas reduction left after step 5	Total electricity left after step 4- Off-site supply electricity needed	m3/month	Auxiliary
Total gas reduction from step 5	Off-site supply electricity needed	m3/month	Auxiliary
Total electricity reduction left after step 5	Total gas left after step 4- Off-site supply gas needed	kWh/ Month	Auxiliary
Total electricity reduction from step 5	Off-site supply gas needed	kWh/ Month	Auxiliary

APPENDIX 11 – CONNECTION BETWEEN TECHNOLOGIES

TABLE 1 – OVERVIEW TECHNOLOGIES

		Step 1.1	Step 1.2	Step 2	Step 3	Step 4
Heating (m3)	Insulation	√				
	HR107 gas reduction		√			
	Gas heating pump				√	
	Heat cold storage				√	
	HRe system		√			
	Bio boiler			√		
	Biogas - cogeneration					√
	Biogas					√
	Sun shading		√			
Cooling (kWh)	Dew point cooling		√			
	Heating pump				√	
	Heat cold storage				√	
	Sun shading		√			
Ventilation (kWh)	Demand controlled ventilation		√			
Lighting (kWh)	New lighting		√			
	Sun shading		√			
Electricity (general)	Solar panels			√	√	√
	Wind turbine					√
	Biogas installation					√
	HRe system			√		

Table 1 shows the overview of the technologies that are used in the Vensim model. Per energy stream, the technologies are summarized. The difference in colours show that the technologies are connected. For example; insulation is not connected with the other heating reduction technologies, whereas HR107, HRe, gas heating pump, bio boiler are connected. Next, the different decision in the system is discussed.

Heating – for heating there are nine possibilities regarding optimization and generation. Two optimizations are not connected with the other technologies such as sun shading and insulation, these steps will be done in all cases. The second step is reducing the heating demand by installing energy efficiency measures. The efficiency technologies are a HR107 boiler, a gas heating pump and a heat cold storage (thermal storage). These steps will be applied before the generation of renewable energy. For the generation of renewable energy there are four options; HRe system, bio boiler, a biogas installation or a biogas installation including cogeneration.

The choice of boiler systems (e.g HR107, HRe system and bio boiler) depends on different aspects. The first choice in boiler system is the bio boiler, however if that is not possible than the decision is between HR107 boiler or a HRe system. The choice between HRe system and HR107 is based on two aspects, the first aspect is the gas demand. If there is a demand of less than 200.000 m^3 then the HR107 is the best choice. If the demand is higher than the stated value, than HRe system is better to use. Besides that, HRe system is a mini cogeneration system this means that it also generates electricity, however the gas demand will increase if this is applied. Which means that the second aspect is the payback time of the HRe system, if it is less than 10 year it can be applied, if not the system will go out.

For the generation of heating there is a choice between solar panels, wind turbines and biogas with cogeneration or solely biogas. The first decision in the model is made by looking at what energy streams are left, if there is only a gas demand left, then the choice is first for a system optimization before generation. This means that first a gas heating pump is applied and then the remaining gas demand is generated by a biogas installation. If there is besides a gas demand, also an electricity demand left than the first choice is a heat cold storage (only if there is a cooling/ventilation demand left). If that is not enough the remaining energy demand is generated with a biogas installation in combination with a cogeneration system, this generates the remaining electricity and gas. If there is only electricity left than the first choice is solar panels and wind turbines. Depending on the energy stream that is left, the choice is between solar panels or wind turbines. If the demand can be compensated by solely solar panels or wind turbines than either the technologies are chosen. If it is not enough, both techniques are used.

Cooling – for the cooling there is one technology which doesn't interact with other technologies namely sun shading, as earlier discusses this will always be applied. For the reduction of the cooling there are three possibilities, the use of dew point cooling, a heating pump and heat cold storage. The first choice is for the optimization of the current system by using an airco heating pump, if there is still a cooling demand left, it will be supplemented with dew point cooling. The heat cold storage as mentioned earlier, will be used when there is both a cooling and heating demand left.

Ventilation – for the reduction of the ventilation demand, there is only one possibility which is a demand controlled system. If there is still electricity left. It will be compensated with the electricity generated from the last row of table 1 – electricity general.

Lighting – for the lighting there are two possibilities which are a new lighting system including daylight depended system and presence detection and sun shading system. Both are applied in any case.

Electricity (general) – for the generation of electricity there are three on-site and/or off-site possibilities and one system optimization. The HRe system is discusses earlier, and will not be further explained here. For the generation of electricity the first choice is generation on the building and on-site. The only possibility for this is the use of solar panels. In the case of off-site generation the first choice is for a windmill, a windmill needs less space and produces more energy than solar panels can. If both solutions are not enough, the biogas installation can be used to generate electricity.

APPENDIX 12 – OVERVIEW TECHNOLOGIES ON THE NEXT PAGE

APPENDIX 12 – OVERVIEW TECHNOLOGIES

01 Building optimization

Option no.	ZEB supply side options	Unit	Energy reduction	Limitations values	Cost reduction after investment	Investment costs (incl. labor costs)	Pay-back time	Reference	Reason for (not) choosing the product
1	**Structural insulation**								
1.1	Insulation building envelope			Rc= 4,00					
1.1.1	uninsulated -> cavity wall insulation	m2	8,00 / m3 / m2 / year	Rc= 1,70	€ 5,40 / year / m2	€ 19,00 /m2	3-4 year(s)	Milieucentraal (2015)	Minimum effect, but optimal option
1.1.2	uninsulated -> outside wall insulation	m2	10,50 / m3 / m2 / year	Rc= 4,00	€ 7,00 / year / m2	€ 130,00 /m2	15 year(s)	Milieucentraal (2015)	In many cases not an option, change in appearance
1.1.3	uninsulated -> inside wall insulation	m2	10,00 / m3 / m2 / year	Rc= 2,50	€ 6,50 / year / m2	€ 100,00 /m2	13 year(s)	Milieucentraal (2015)	Payback time = 13 years > 10 years
1.2	Insulation roof			Rc= 6,00					
1.2.1	Roof, slobed	m2	9,00 / m3 / m2 / year	Rc= 4,00	€ 7,00 / year / m2	€ 64,00 / m2	5 year(s)	Milieucentraal (2015)	No higher value than Rc=4 applied yet
1.2.2	Roof, flat	m2	10,00 / m3 / m2 / year	Rc= 4,00	€ 7,00 / year / m2	€ 60,00 / m2	3-5 year(s)	Milieucentraal (2015)	No higher value than Rc=4 applied yet
1.3	Insulation floor			Rc= 3,50					
1.3.1	No insulation --> insulation	m2	5,70 / m3 / m2 insulation /year	Rc= 3,50	€ 2,72 / year / m2	€ 33,33 / m2	5-8 year(s)	Milieucentraal (2015)	Boundaries are met
1.4	Insulation windows (basis is single glazing)			U= 1,80					
1.4.1	Secondary frame with coating	m2	16,30 / m3 gas/ m2 glazing / year	U= 1,80	€ 7,00 / year (per m2 glass)	€ 115,00 / m2	4-5 year(s)	Hadeko trading company (2015)	Lowest U- value
1.4.2	HR	m2	16,30 / m3 gas/ m2 glazing / year	U= 1,7-2,0	€ 9,00 / year (per m2 glass)	€ 120,00 / m2	4-5 year(s)	Hadeko trading company (2015)	Boundaries are met, but not best cost/energy reduction ratio
1.4.3	HR+	m2	20,80 / m3 gas/ m2 glazing / year	U= 1,3-1,6	€ 11,00 / year (per m2 glass)	€ 125,00 / m2	4-5 year(s)	Hadeko trading company (2015)	Highest cost/energy reduction ratio, boundaries are met
1.4.4	HR++	m2	23,10 / m3 gas/ m2 glazing / year	U= 1,20	€ 13,00 / year (per m2 glass)	€ 130,00 / m2	4-5 year(s)	Hadeko trading company (2015)	Too expensive
1.4.5	HR+++	m2	24,50 / m3 gas/ m2 glazing / year	U= 0,5-0,9	€ 14,00 / year (per m2 glass)	€ 170,00 / m2	5-10 year(s)	Hadeko trading company (2015)	Payback time is longer than other products
2	**Installation**								
2.1	Ventillation systems								
2.1.2	Demand controlled ventillation (DCV)	kWh	21,30 / kWh / year / pp		€ 4,90 / year / pp	€ 2.000,00 / system	1-5 year(s)	Duurzaammkb (2014)	
2.2	Heating systems		Power supplied	Efficiency heat-loss					
2.2.1	CV 100 kW	m3	6,59 kWh / m3 gas	0,75 %	€ 422,00 / year	€ 5.000,00 / system	2-5 year(s)	Duurzaammkb(2014)	Not most efficient system
2.2.2	VR 100 kW	m3	7,30 kWh / m3 gas	0,83 %	€ 400,00 / year	€ 1.200,00 / system	3 year(s)	Duurzaammkb(2014)	Not most efficient system
2.2.3	HR 100 kW	m3	9,41 kWh / m3 gas	1,07 %	€ 1.666,67 / year	€ 5.000,00 / system	2-5 year(s)	Duurzaammkb(2014)	Most efficient system
2.3	Cooling systems			COP					
2.3.1	Compression cooling (45 kW)	kWh	37,50 kWh / m2 / year	3	€ 8,63 / m2 / year	€ 6.750,00 / system	5-7 year(s)	NEN 2916	Lowest COP value
2,3,2	Dew point cooling (45 kW)	kWh	47,50 kWh / m2 / year	18	€ 10,93 / m2 / year	/ system	3-5 year(s)	AgentschapNL (2011)	Highest COP value
2.4	Lighting (standard 140 W)								
2.4.1	Standard bulb replacement (76 W)	kWh	160,00 / kWh / year / bulb	-	€ 160,00 / year / bulb	€ 15,60 / bulb	0,5 year(s)	Philips (2010)	Lowest energy reduction
2.4.2	Previous + daylightdependent lighting control	kWh	217,00 / kWh / year / bulb	-	€ 217,00 / year / bulb	€ 45,00 / bulb	4 year(s)	Philips (2010)	Lower energy reduction - cost reduction combination
2.4.3	Previous + presence detection	kWh	274,00 / kWh / year / bulb	-	€ 332,29 / year / bulb	€ 45,00 / bulb	4 year(s)	Philips (2010)	Highest energy reduction - cost reduction combination
2.5	Sunshading				Not possible to give (influences both gas as elektricity)				
2.5.1	(basic situation), no automatic system	MJ	245,00 / MJ / m2 / year		Not applicable	€ 0,00 / m2 / screen	year(s)	TNO (2011)	-
2.5.2	External Venetian blinds (manual)	MJ	-20,00 / MJ / m2 / year		Not applicable	€ 355,00 / m2 / screen	3-4 year(s)	TNO (2011)	No reduction, increase in energy use
2.5.3	External Venetian blinds (200 w/m2)	MJ	32,83 / MJ / m2 / year		Not applicable	€ 400,00 / m2 / screen	3-4 year(s)	TNO (2011)	Not optimal return rate
2.5.4	External Venetian blinds (350 w/m2)	MJ	43,12 / MJ / m2 / year		Not applicable	€ 420,00 / m2 / screen	3-4 year(s)	TNO (2011)	Not optimal return rate
2.5.5	External screens (manual)	MJ	-65,00 / MJ / m2 / year		Not applicable	€ 400,00 / m2 / screen	6 year(s)	TNO (2011)	No reduction, increase in energy use
2.5.6	External screens (200 w/m2)	MJ	38,96 / MJ / m2 / year		Not applicable	€ 510,00 / m2 / screen	3-5 year(s)	TNO (2011)	Not optimal return rate
2.5.7	External screens (350 w/m2)	MJ	56,60 / MJ / m2 / year		Not applicable	€ 520,00 / m2 / screen	3-5 year(s)	TNO (2011)	Best return rate regarding energy use

02 Energy generation building footprint

Option no.	ZEB supply side options	Unit	Energy reduction	Limitations values	Cost reduction after investment	Investment costs (incl. labor costs)	Pay-back time	Reference	Reason for (not) choosing the product
3	**Renewable energy generation - elektricity**								
3.1	Solarpanels								
3.1.1	Solarpanels south oriented (265 Wp) 35°-36°	m2	0,23 kWh/solarhour/panel/year	0,85 / kWh	€ 51,81 / panel / year	€ 450,00 / panel	9 year(s)	Solsolutions (2015)	Boundaries are met
3.1.2	Solar panels south oriented (265 Wp) 20°-34°	m2	0,21 kWh/solarhour/panel/year	0,808 / kWh	€ 49,22 / panel / year	€ 450,00 / panel	9 year(s)	Solsolutions (2015)	Boundaries are met
3.1.3	Solar panels south oriented (265 Wp) 37°-60°	m2	0,21 kWh/solarhour/panel/year	0,81 / kWh	€ 49,37 / panel / year	€ 450,00 / panel	9 year(s)	Solsolutions (2015)	Boundaries are met
3.1.4	Solar panels east/west oriented (265 Wp) 35°-36°	m2	0,19 kWh/solarhour/panel/year	0,72 / kWh	€ 43,88 / panel / year	€ 450,00 / panel	10 year(s)	Solsolutions (2015)	Boundaries are met
3.1.5	Solar panels east/west oriented (265 Wp) 20°-34°	m2	0,18 kWh/solarhour/panel/year	0,68 / kWh	€ 41,45 / panel / year	€ 450,00 / panel	11 year(s)	Solsolutions (2015)	Pay-back time too high
3.1.6	Solar panels east/west oriented (265 Wp) 37°-60°	m2	0,18 kWh/solarhour/panel/year	0,68 / kWh	€ 41,45 / panel / year	€ 450,00 / panel	11 year(s)	Solsolutions (2015)	Pay-back time too high
3.2	Small windturbines on roof								
3.2.1	0.5 kW (1 m width)	kWh	504,00 kWh / year	-	€ 115,92 / year / turbine	€ 9.239,00 / turbine	80 year(s)	Duurzame-energiebronnen (2014)	Poor cost/return ratio
3.2.2	0.6 kW (1.7 m width)	kWh	189,00 kWh / year	-	€ 43,47 / year / turbine	€ 8.925,00 / turbine	205 year(s)	Duurzame-energiebronnen (2014)	Poor cost/return ratio
3.2.3	1.4 kW (2 m width)	kWh	49,00 kWh / year	-	€ 11,27 / year / turbine	€ 4.324,00 / turbine	384 year(s)	Duurzame-energiebronnen (2014)	Poor cost/return ratio
3.3	Solar heater								
3.3.1	Solar heater (300 - 400 liters)	m3	80,00 m3 / m2 suncollector / year	-	€ 60,00 / m2 / year	€ 15.500,00 / system	15 year(s)	Duurzaam MKB (2014)	Pay-back time too high
3.4	Cogeneration (WKK)								
3.4.1	HRE 22 kW	m3	12,31 kWh / m3 gas	1,40 %	€ 1.375,00 / year	€ 11.000,00 / system	8 year(s)	Duurzaammkb(2015)	Generates elektricity besides using gas

03 Energy generation on-site

Option no.	ZEB supply side options	Unit	Energy reduction		Cost reduction after investment	Investment costs	Pay-back time	Referentie	Reason for choosing which element
4	**Renewable energy generation - heating**								
4.1	Heating pumps			Efficiency					
4.1.1	Air / water heat pump (heating house)	kWh	3,10 per kWh	310 %	€ 2,02 / per kWh	€ 15.000,00 / installation	<10 year(s)	SenterNovem (2015)	Investment costs to high
4.1.2	Air / air heat pump (airconditioners)	kWh	2,90 per kWh	290 %	€ 1,89 / kWh	€ 8.000,00 / installation	4 year(s)	SenterNovem (2015)	Best cost/return ratio
4.1.3	Water / water heat pump (el.)	kWh	4,65 per kWh	465 %	€ 3,02 / kWh	€ 20.000,00 / installation	<10 year(s)	SenterNovem (2015)	Investment costs to high
4.1.4	Soil / water heat pump - horizontal	kWh	per kWh	%	€ - / kWh	€ 4.000,00 / installation	<10 year(s)	SenterNovem (2015)	On-site has to be 1.5 as big as the surface that needs to be heated
4.1.5	Soil / water heat pump - vertical	kWh	per kWh	%	€ - / kWh	€ 17.500,00 / installation	<10 year(s)	SenterNovem (2015)	Investment costs to high
5.1	Solarpanels								
5.1.1	Solarpanels south oriented (265 Wp) 35°-36°	m2	0,23 kWh/solarhour/panel/year	0,85 / kWh	€ 51,81 / panel / year	€ 450,00 / panel	9 year(s)	Solsolutions (2015)	Boundaries are met
5.1.2	Solar panels east/west oriented (265 Wp) 35°-36°	m2	0,19 kWh/solarhour/panel/year	0,72 / kWh	€ 43,88 / panel / year	€ 450,00 / panel	10 year(s)	Solsolutions (2015)	Boundaries are met
5.2	Small windturbines								
5.2.1	1.8 kW (3.7 m, hight 10 meters)	kWh	1827,00 kWh / year	-	€ 420,21 / turbine / year	€ 11.000,00 / turbine	26 year(s)	Duurzame-energiebronnen (2014)	Poor cost/return ratio
5.2.2	5 kW (500 m)	kWh	2352,00 kWh / year	-	€ 540,96 / turbine / year	€ 25.900,00 / turbine	48 year(s)	RVO NL(2012)	Poor cost/return ratio
5.2.3	10 kW (500 m)	kWh	12000,00 kWh / year	-	€ 2.760,00 / turbine / year	€ 32.000,00 / turbine	11,6 year(s)	RVO NL(2012)	Poor cost/return ratio
6.1	Biogass boiler								
6.1.1	Biogas boiler 600 kW	m3	(complete reduction of heating demand)		€ 7,00 / m3 gas	€ 315.000,00 / system	5 year(s)	Groenopgewekt.nl (2015)	Payback time is within boundaries

04 Energy generation off-site

Option no.	ZEB supply side options	Unit	Energy reduction	Limitations values	Cost reduction after investment	Investment costs	Pay-back time	Referentie	Reason for choosing which element
8	**Renewable energy generation**								
8.1	Heat cold storage (WKO)								
8.1.1	Closed heat cold storage (small offices)	GJ	0,71 / 1 kW		57%	€ 600.000,00 / system	3-7 year(s)	wkotool.nl	Both, some cases an open system is better, sometimes closed better
8.1.2	Open heat cold storage (offices)	GJ	0,77 / 1 kW		54%	€ 600.000,00 / system	3-7 year(s)	wkotool.nl	Both, some cases an open system is better, sometimes closed better
8.2	Biogass installation								
8.2.1	Small biogass installation	m3	110.000 / natural gas / year		€ 71.500,00 / year	€ 2.000,00 / kW	8 year(s)	Biomassa.eu (2014)	Can fully take over the heating demand
8.2.2	Small biogass installation - cogeneration	kWh	300 MWh elektrcity / year		€ 69.000,00 / year	€ 3.000,00 / kW	5-6 year(s)	Biomassa.eu (2014)	Can fully take over the heating / electricity demand
		m3	900 MWh heating / year		€ 207.000,00 / year	€ 3.000,00 / kW	5-6 year(s)	Biomassa.eu (2014)	Can fully take over the heating / electricity demand
8.3	Big windturbines								
8.3.1	1 MW	kWh	2.000.000 / year / turbine	-	€ 460.000 / turbine / year	€ 1.500.000,00	3,3 year(s)	Windpark.nu (2015)	Best cost/return ratio
8.3.2	3 MW	kWh	6.000.000 / year / turbine	-	€ 1.380.000 / turbine / year	€ 4.500.000,00	3,3 year(s)	Windpark.nu (2015)	Investment kost is higher then 1MW windmill

APPENDIX 13 – DEMAND CURVES

As explained in chapter 4, the heating, cooling, DWH, moistening, lighting, electronica, pumps and ventilation all have a different demand curve. Below, these demands are described and how they are modelled in the Vensim model. Before discussing how the curves are constructed, the explanation of the roles between the curves and the percentage of the demand is discussed (see figure 1). If the percentage of each electricity and gas demanded system is known, the curves are multiplied by the percentage per demand system. The curves explained below all have a sum of 1, which means that by multiplying them with the percentage of each system, the percentage is divided, following the curves.

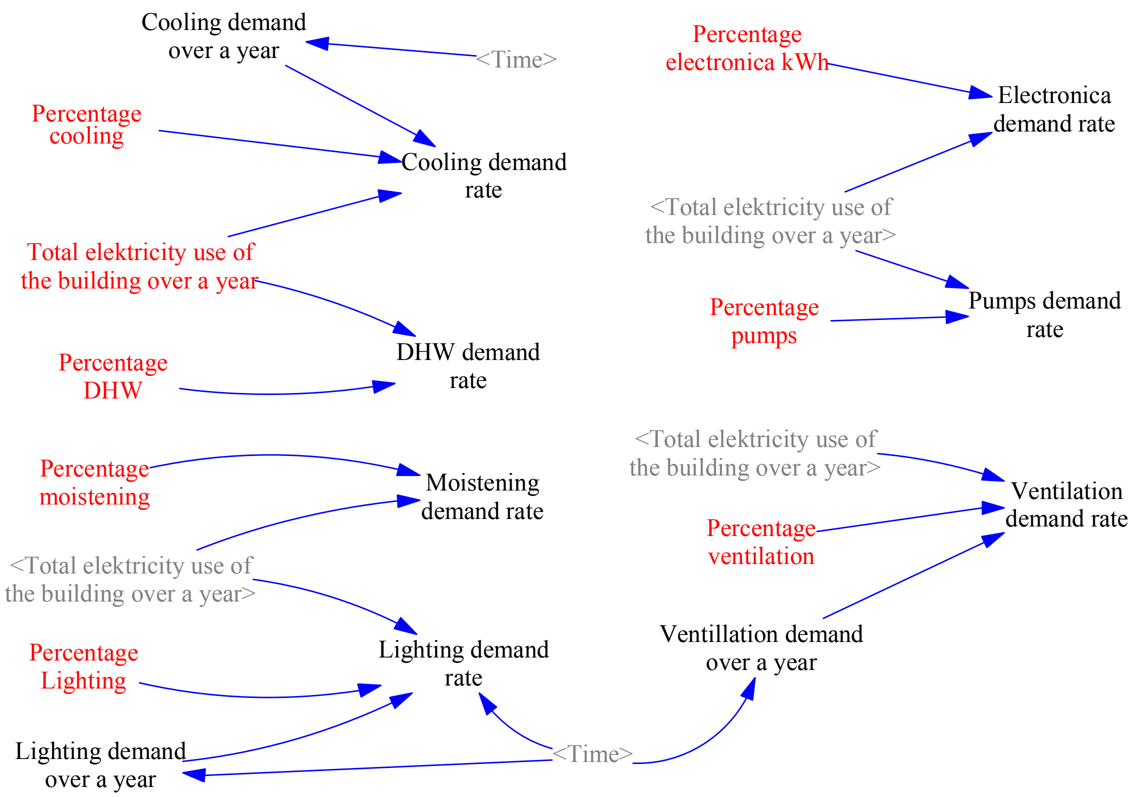


FIGURE 1 – DEMAND OF THE BUILDING

Heating - the heating demand curve is based on the average temperature in the Netherlands using the KNMI database as source. In the winter the heating demand is the highest, and in the summer the lowest. Table 1 shows the average temperature throughout the year and the column next to the temperature shows the deviation based on the temperature. Together this form the heating demand shown in figure 2. The curve is also checked with data from a building (Heijmans, 2015) where the gas demand is fully from the heating demand, this curve corresponds with the gas demand. The figure can be read as following, on the x axis the months are shown from 0 which corresponds with January till 11 which corresponds with December. On the y axis the deviation from table 1 is shown. This figure is repeated (with different deviations) for figure 3 till 5.

TABLE 1 – INFORMATION HEATING DEMAND CURVE

Month	Temperature [°C]	Deviation [%]
0) January	5.7	0.188
1) February	6.5	0.170
2) March	8.4	0.151
3) April	12.1	0.095
4) May	13.2	0.050
5) June	16.2	0.021
6) July	19.8	0.003
7) August	16.1	0.006
8) September	15.9	0.034
9) October	13.4	0.058
10) November	8.2	0.101
11) December	4.8	0.123

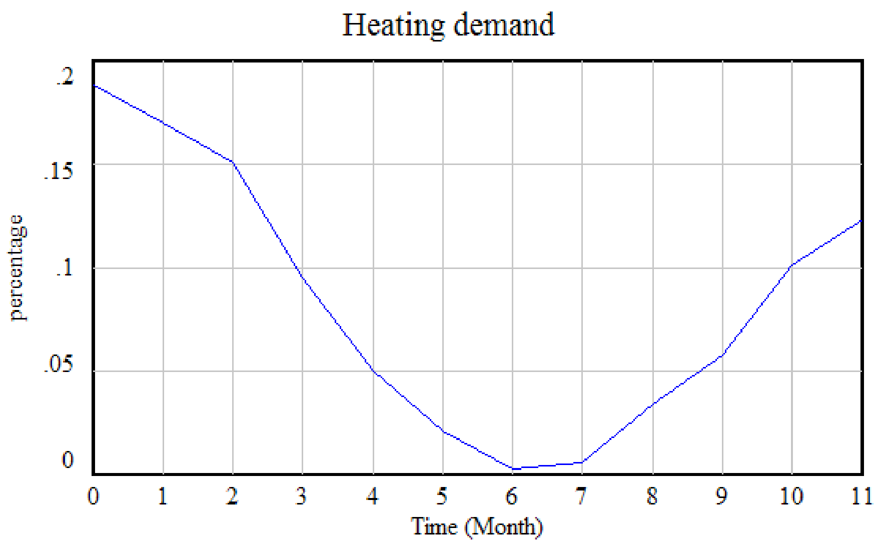


FIGURE 2 - HEATING DEMAND CURVE

Cooling - The cooling demand curve is also based on the average temperature in the Netherlands using the KNMI (2014) database as source. In the winter the cooling demand is the lowest, and in the summer the highest. Table 1 shows the average temperature throughout the year and the column next to the temperature shows the deviation based on the temperature. Together this form the cooling demand, see figure 3.

TABLE 2 – INFORMATION COOLING DEMAND CURVE

Month		Temperature [°C]	Deviation [%]
1)	January	5.7	0.041
2)	February	6.5	0.046
3)	March	8.4	0.060
4)	April	12.1	0.086
5)	May	13.2	0.094
6)	June	16.2	0.115
7)	July	19.8	0.141
8)	August	16.1	0.115
9)	September	15.9	0.113
10)	October	13.4	0.096
11)	November	8.2	0.058
12)	December	4.8	0.034

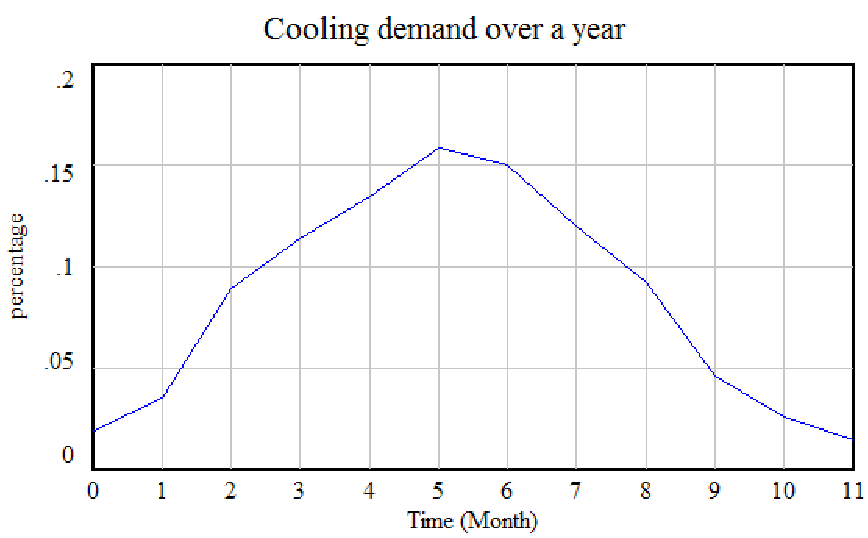


FIGURE 3 - COOLING DEMAND CURVE

Lighting - The lighting demand curve is based on the solar hours per month, based on the KNMI (2014) database. In the winter the lighting demand is the highest, and in the summer the lowest. Table 3 shows the average solar hours throughout the year and the column next to the solar hours shows the deviation. Figure 4 shows the lighting demand, based on the deviation per month.

TABLE 3 – INFORMATION LIGHTING DEMAND CURVE

Month		Solar hours [h]	Deviation [%]
0)	January	20	0.089
1)	February	36	0.088
2)	March	93	0.083
3)	April	119	0.081
4)	May	141	0.079
5)	June	166	0.076
6)	July	156	0.077
7)	August	125	0.080
8)	September	96	0.083
9)	October	48	0.087
10)	November	27	0.089
11)	December	15	0.090

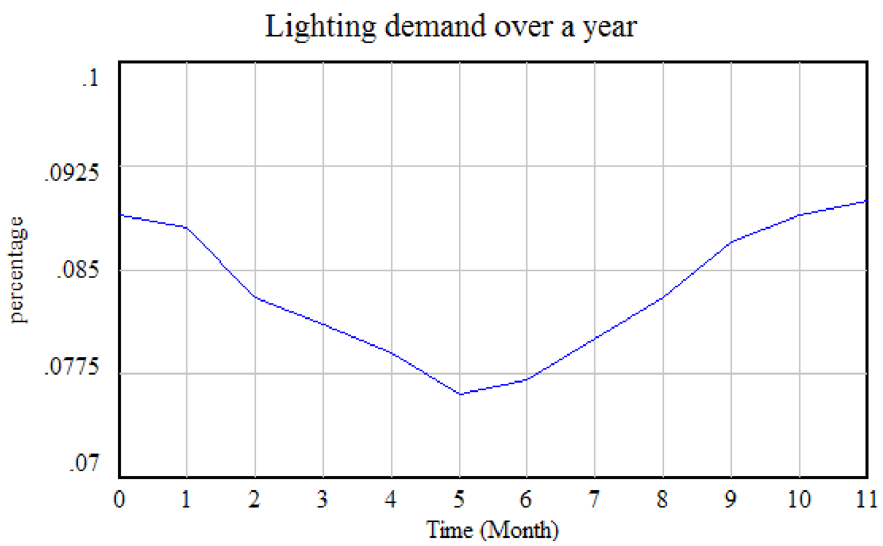


FIGURE 4 - LIGHTING DEMAND CURVE

Ventilation - The ventilation demand of a building varies throughout the year. For the deviation in ventilation, a source is used who is specialized in ventilation systems (S&P, 2014) and showed when ventilation is needed throughout a year, for an office building. Table 4 shows what the average energy use is for an office building per month, from that information the deviation is made in the column next to it. The result of the deviation is shown in figure 5.

TABLE 4 – INFORMATION VENTILATION DEMAND CURVE

Month		Energy use [kWH]	Deviation [%]
0)	January	6636	0.190
1)	February	5760	0.173
2)	March	0	0.000
3)	April	0	0.000
4)	May	3168	0.095
5)	June	3024	0.091
6)	July	3168	0.095
7)	August	1152	0.035
8)	September	0	0.000
9)	October	0	0.000
10)	November	6048	0.182
11)	December	4608	0.139

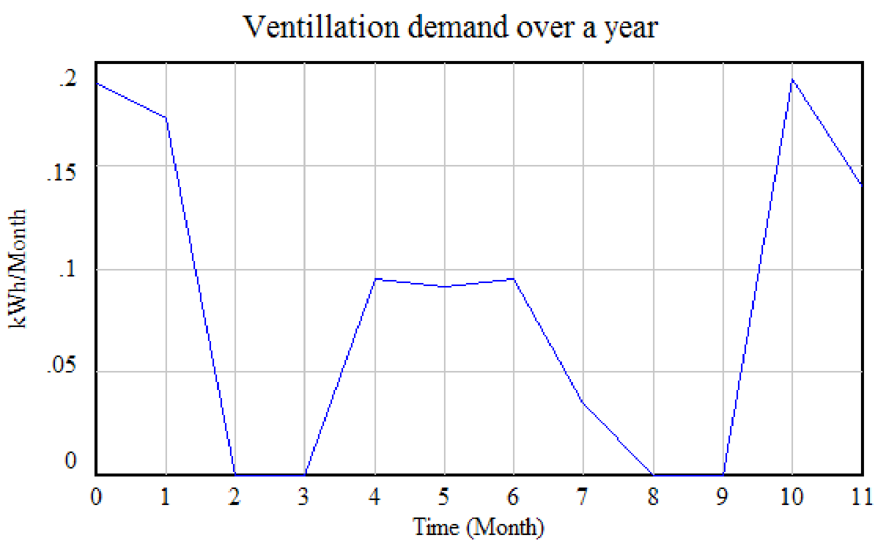


FIGURE 5 - VENTILATION DEMAND CURVE

DWH, Moistening, electronica and pumps - For the DWH system, no curve is needed. A DWH system is needed throughout the whole year. In this case the percentage of the total electricity demand can be used and no demand curve is needed. For the moistening of the building, also no curve is needed. Moistening is also needed throughout the whole year, the deviation in moistening is that low that no curve is needed. Regarding electronica, each device is used during the whole year, so also for the electronica no curve is needed and the average is used as basis. The pumps in a building are also on during the whole year and no variation is needed.

APPENDIX 14 – USER INTERFACE

Prepare input and simulation		
Initial situation		
0.1	0 – 300000 Total gas use of the building over a year	What is the total gas use of the building over a year in m^3
0.2	0 – 200000 Total elektricity use of the building over a year	What is the total electricity use of the building over a year in kWh
0.3	0 – 1 Percentage DHW	What percentage of the electricity/gas use is due to the DWH?
0.4	0 – 1 Percentage electronica kWh	What percentage of the electricity use is due to the electronica?
0.5	0 – 1 Percentage electronica m3	What percentage of the gas use is due to the electronica?
0.6	0 – 1 Percentage Lighting	What percentage of the electricity use is due to lighting?
0.7	0 – 1 Percentage of heating	What percentage of the electricity/gas use is due to the heating?
0.8	0 – 1 Percentage moistening	What percentage of the electricity/gas use is due to moistening?
0.9	0 – 1 Percentage pumps	What percentage of the electricity/gas use is due to the pumps?
0.10	0 – 1 Percentage ventilation	What percentage of the electricity/gas use is due to ventilation?
0.11	0 – 1 Percentage cooling	What percentage of the electricity/gas use is due to cooling?
Step 1 - Fill in the data for building optimization described in step 1.1-1.1.16 below:		
Cavity wall insulation		
1.1	0 – 7 Rc value wall	Fill in the Rc value of the wall
1.2	0 – 1 Availability cavity wall	Is the cavity wall available for insulation, either yes=1 or no=0

1.3	0 100,000 Total surface area wall	Fill in the total surface area of the wall in square meters
Roof insulation		
1.4	0 1 Availability roof insulation	Fill in If the roof has the possibilities for insulation, either yes=1 or no=0
1.5	0 7 Rc value of roof	Fill in the Rc value of the roof
1.6	0 1 Usable roof is flat	Fill in if the roof is flat, either yes=1 or no=0
1.7	0 100,000 Total surface area flat roof	Fill in the total surface area of the roof that is flat in square meters
1.8	0 1 Usable roof is sloping	Fill in if the roof is sloping, either yes=1 or no=0
1.9	0 10,000 Total surface area sloping roof	Fill in the total surface area of the roof that is sloping in square meters
Floor insulation		
1.10	0 100,000 Total surface area floor	Fill in the total surface area of the floor(s) in the building in square meters
1.11	0 100 Crawlpace height	Fill in the crawls pace height under the building in cm, if there is no crawls pace then fill in 0
1.12	0 7 Rc value of floor	Fill in the Rc value of the floor
Window insulation		
1.13	0 1000 "Total surface area windows - single glazing"	Fill in the total surface are of the windows who have single glazing in square meters
1.14	0 1000 "Total surface area windows - double glazing"	Fill in the total surface are of the windows who have double glazing in square meters
1.15	0 1000 "Total surface area windows - HR+ glazing"	Fill in the total surface are of the windows who have HR+ glazing in square meters
1.16	0 1000 "Total surface area windows - single glazing"	Fill in the total surface are of the windows who have HR++ glazing in square meters

Step 2 - Fill in the data for system optimization described in step 2.1-2.14 below:		
Demand controlled ventilation		
2.1	0 2 Current system program	Fill in if the current ventilation system is on during the whole year or only during office hours. whole year=0 and office hours=1
2.2	0 3000 Total capacity building	Fill in what the maximum capacity (numbers of people) is in the building
2.3	0 10,000 Average occupancy per hour	What is the average occupancy of the building?
HR107 heating system		
2.4	0 3 "System type (1)"	Fill in what type of system is used for heating: 1= CV, 2= VR, 3= HR, 4= HRe
2.5	0 800 "System capacity (1)"	Fill in what the capacity is of the building in kWh
2.6	0 3 "System type (2)"	Fill in what type of system is used for heating: 1= CV, 2= VR, 3= HR, 4= HRe
2.7	0 800 "System capacity (2)"	Fill in what the capacity is of the building in kWh
Dew point cooling system		
2.8	0 2 Amount of workdays above 15 degrees	Fill in what type of system that is currently used for cooling, either Compression cooling=1 or dew point cooling=2
Lighting optimization		
2.9	0 .02 Power initial lighting per m2	Fill in what the power is of the current lighting system in kW per square meters
2.10	0 1 Presence detection present	Is there currently presence detection present? If yes, fill in 1 if no, fill in 0.
2.11	0 1 Daylight dependent lighting present	Is there currently daylight dependent lighting present? If yes, fill in 1 if no, fill in 0.
Sun shading		
2.12	0 1 No sunshading	Fill in if there is sun shading present, if not fill in 0 if yes fill in 1.

2.13	0 1 "Manual blinds / coating"	Fill in if there are manual blinds or coating on the glazing, if not fill in 0 if yes fill in 1.
2.14	0 1 Automatic blinds	Fill in if there are automatic blinds, if not fill in 0 if yes fill in 1.
Step 3 - Fill in the data for generation on building footprint described in step 3.1-3.4 below:		
Solar panels		
3.1	0 1 Roof can be used for solar panels	Fill in if the roof of the building can be used for solar panels (e.g. construction), either yes=1 or no=0.
3.2	0 1 Roof is south oriented	Fill in what the orientation is of the building if it is south, then fill in yes=1 or if not fill in no=0.
3.3	0 1 "Roof is east/west oriented"	Fill in what the orientation is of the building if it is east/west, then fill in yes=1 or if not fill in no=0.
3.4	0 180 Sloping of roof	Fill in what the sloping is of the roof in degrees
Step 4 - Fill in the data for generation on-site described in step 4.1-4.6 below:		
Solar panels		
4.1	0 1 Site can be used for solar panels	Fill in if the site can be used for solar panels (e.g. no trees or other shadows), either yes=1 or no=0
4.2	0 1000 "Total usable surface area on-site"	Fill in the total surface area that can be used for solar panels in square meters
4.3	0 1 Panels are south oriented	Fill in what the best orientation is for solar panels if it is south, then fill in yes=1 or if not fill in no=0.
4.4	0 1 "Panels are east/west oriented"	Fill in what the best orientation is for solar panels if it is east/west, then fill in yes=1 or if not fill in no=0.
Bio boiler		
4.5	0 1 Space available for bio boiler	Fill in if there are limitations for installing a biomass boiler (e.g. space for wood) if there is space fill in yes=1 or if not fill in no=0.

Heat cold storage		
4.6	0 1 Ground is suitable for heat cold storage	Check with the help of www.wkotool.nl if the location is suitable for a heat cold storage system
Step 5 - Fill in the data for generation on-site described in step 5.1-5.5 below:		
Wind turbines		
5.1	0 10 Number of windtubines	Fill in the number of wind turbines that can be put on the surrounding areas.
Solar panels off-site		
5.2	0 1 "Off-site location can be used for solar panels"	Fill in if the off-site location can be used for solar panels (e.g. no trees or other obstacles).
5.3	0 100,000 "Total usable surface area off-site"	Fill in the total area that can be used for solar panels in square meters
5.4	0 1 "Panels off-site can be south oriented"	Fill in if the panels can be placed in a south direction
5.5	0 1 "Panels off-site can be east/west oriented"	Fill in if the panels can be placed in an east or west orientation if south orientation is not possible.
Step 6 – Adjust time boundaries (model > settings) and run the model		
Step 7 – Interpret the output window		

APPENDIX 15 – VARIABLES USER INTERFACE

00 initial situation			
NAME	EQUATION	UNIT	TYPE
Total gas use of the building over a year	m^3 gas demand over a year (total)	m^3	Constant
Total electricity use of the over a year	kWh electricity demand over a year (total)	kWh	Constant
Cooling	Percentage of the electricity or gas use	%	Constant
DHW	Percentage of the electricity or gas use	%	Constant
Moistening	Percentage of the electricity or gas use	%	Constant
Lighting	Percentage of the electricity or gas use	%	Constant
Equipment	Percentage of the electricity or gas use	%	Constant
Pumps	Percentage of the electricity or gas use	%	Constant
Ventilation	Percentage of the electricity or gas use	%	Constant
01 Building optimization			
Availability cavity wall	Either 1=yes, 0=no	-	Constant
Total surface area wall	Value square meters	m^2	Constant
Rc value wall	Rc value of the wall	-	Constant
Availability roof insulation	Either 1=yes, 0=no	-	Constant
Rc value of the roof	Rc value of the roof		Constant
Total surface area flat roof	Value square meters	m^2	Constant
Usable roof is flat	Either 1=yes, 0=no	-	Constant
Total surface area sloping roof	Value square meters	m^2	Constant
Usable roof is sloping	Either 1=yes, 0=no	-	Constant
Total surface area floor	Value square meters	m^2	Constant
Crawlspace height	Value cm	cm	Constant
Rc value of floor	Rc value of the wall	-	Constant
Total surface area windows - HR++ glazing	Value square meters	m^2	Constant
Total surface area windows - HR+ glazing	Value square meters	m^2	Constant
Total surface area windows - double glazing	Value square meters	m^2	Constant
Total surface area windows - single glazing	Value square meters	m^2	Constant

01 System optimization			
Average occupancy	Average occupancy of the building per day	-	Constant
Total capacity building	Total persons capacity of the building	Persons	Constant
Current system program	Either: 0=system is on the whole year or 1=system is on during office hours	-	Constant
System capacity (1)	Capacity system in kWh	kWh	Constant
System type (1)	Either 1= CV, 2= VR, 3= HR, 4= HRe	-	Constant
System capacity (2)	Capacity system in kWh	kWh	Constant
System type (2)	Either 1= CV, 2= VR, 3= HR, 4= HRe	-	Constant
Volume of building	Volume in m^3	m^3	Constant
Type of cooling system	Either 1 = Compression cooling or 2 = Dew point cooling	-	-
Power initial lighting per m^2	Amount in kW/year	kW/m^2	Constant
Presence detection present	Either 1=yes, 0=no	-	Constant
Daylight-dependent lighting control present	Either 1=yes, 0=no	-	Constant
No sun shading	Either 1=yes, 0=no	-	Constant
Manual blinds / coating	Either 1=yes, 0=no	-	Constant
Automatic blinds	Either 1=yes, 0=no	-	Constant
02 Generation on building footprint			
Roof can be used for solar panels	Either 1=yes, 0=no	-	Constant
Roof is south oriented	Either 1=yes, 0=no	-	Constant
Roof is east/west oriented	Either 1=yes, 0=no	-	Constant
Sloping of roof	Degrees of roof	Degrees	Constant
03 Energy generation on-site			
Site can be used for solar panels	Either 1=yes, 0=no	-	Constant
Total usable surface area on-site	Fill in m^2 available on-site	m^2	Constant
Panels are south oriented	Either 1=yes, 0=no	-	Constant
Panels are east/west oriented	Either 1=yes, 0=no	-	Constant
Space available for bio boiler	Either 1=yes, 0=no	-	Constant
Ground is suitable for heat cold storage	Either 1=yes, 0=no	-	Constant
04 Energy generation off-site			
Number of wind turbines	Number of windmills 0,1,2,3 etc.	-	Constant
Off-site location can be used for solar panels	Either 1=yes, 0=no	-	Constant

Total usable surface area off-site	Fill in m^2 available off-site	m^2	Constant
Panels off-site can be south oriented	Either 1=yes, 0=no	-	Constant
Panels off-site can be east/ west oriented	Either 1=yes, 0=no	-	Constant

APPENDIX 16 – QUESTIONNAIRE CASE STUDY

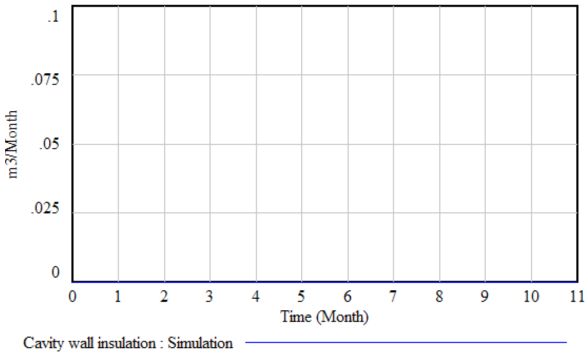
00 Initial situation		
Nr.	Question(s)	Answer
1	What is the total gas use of the building over a year in m^3?	94,403 m^3 gas
2	What is the total electricity use of the building over a year in kWh	1,485,422 kWh electricity
3	What percentage of the electricity/gas use is due to the DWH?	2% electricity
4	What percentage of the electricity use is due to the electronica?	59% electricity
5	What percentage of the electricity use is due to lighting?	18% electricity
6	What percentage of the electricity/gas use is due to the heating?	96.6% gas
7	What percentage of the electricity/gas use is due to moistening?	6% electricity
8	What percentage of the electricity/gas use is due to the pumps?	2% electricity
9	What percentage of the electricity/gas use is due to ventilation?	10% electricity
10	What percentage of the electricity/gas use is due to cooling?	3% electricity
11	What percentage of the gas use is due to the electronica?	3% gas
1.1 Building optimization		
Nr.	Question(s)	Answer
11	What is the Rc value of the wall?	Rc value = 2,5
12	Is the cavity wall available for optimization?	No, moisture ventilation
13	What is the total surface area of the wall?	3878,4 m^2
14	Is the roof available for insulation?	No, moisture ventilation
15	What is the Rc value of the roof?	Rc value = 3
16	Is the roof flat or sloping ?	Flat
17	What is the total surface are of the roof?	1963 m^2
18	What is the Rc value of the floor?	Rc value = 3
19	Is there a crawls pace below the building, if yes how high?	No
20	What is the total surface are of the floor?	10252 m^2
21	What types of windows are used in the building?	HR++ glazing and double glazing
22	What is the total surface are per type of window?	HR++ = 1696 m^2, double glazing = 10 m^2

1.2 System optimization		
Nr.	Question(s)	Answer
23	What is the total capacity of the building?	1025 persons
24	What is the current system program? On during the whole year, or only during office hours?	Office hours
25	What is the average occupancy of the building? (per month)	615,2
26	What type of heating system(s) is present in the building?	HR and VR boiler
27	What is the capacity of the heating system(s) of the building?	HR = 349 kWh , VR = 218 kWh
28	What type of cooling system is present in the building?	Compression cooling
29	What is the power of the lighting per m^2 in the building?	9 watt per m^2
30	Is there presence detection present?	Yes
31	Is there daylight dependent lighting present?	No
32	What type of sun shading is present in the building?	Coating
02 Generation on building footprint		
Nr.	Question(s)	Answer
33	What is the orientation of the roof?	South
34	What is the sloping of the roof?	0 degrees
03 Energy generation on-site		
Nr.	Question(s)	Answer
35	What is the total usable surface area on-site?	0
36	What angle of the surface area can be used for solar panels?	No angle
37	Is there space available for a bio boiler?	Yes
38	Is the ground suitable for heat cold storage?	Yes (WKOtool.nl)
04 Energy generation off-site		
Nr.	Question(s)	Answer
39	What number of wind turbines that can be put on the surrounding areas?	1
40	Fill in if the off-site location can be used for solar panels (e.g. no trees or other obstacles).	yes
41	Fill in the total area that can be used for solar panels in square meters	1000
42	Fill in if the panels can be placed in a south direction	yes
43	Fill in if the panels can be placed in an east or west orientation if south orientation is not possible.	South

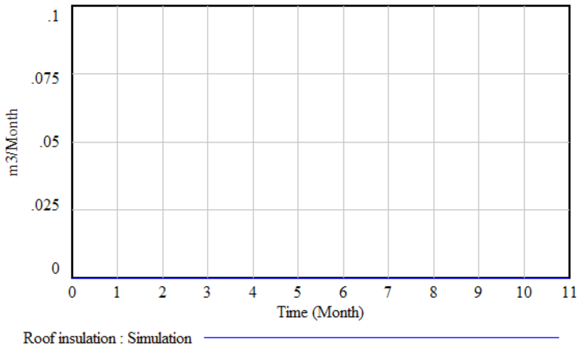
APPENDIX 17 – OUTPUT WINDOW SIMULATION

1.1 building optimization

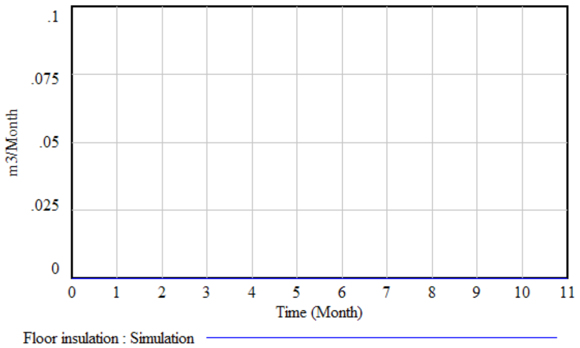
1.1.1 Cavity wall insulation



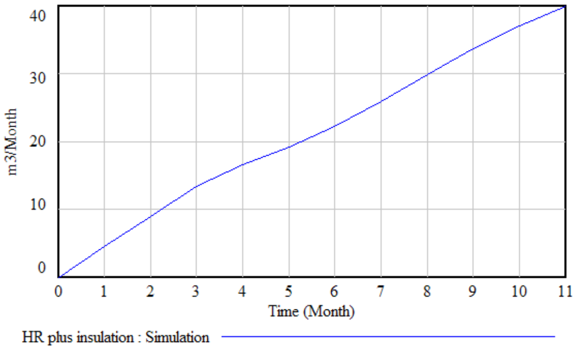
1.1.2 Roof insulation



1.1.3 Floor insulation

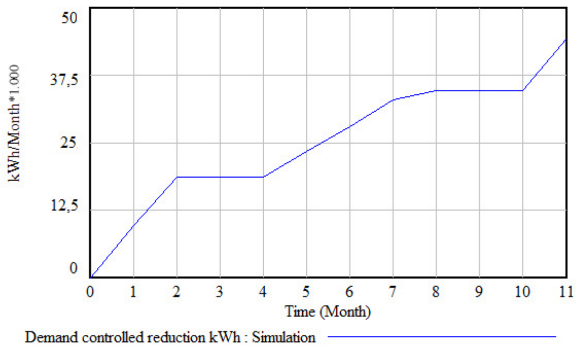


1.1.4 HR plus insulation

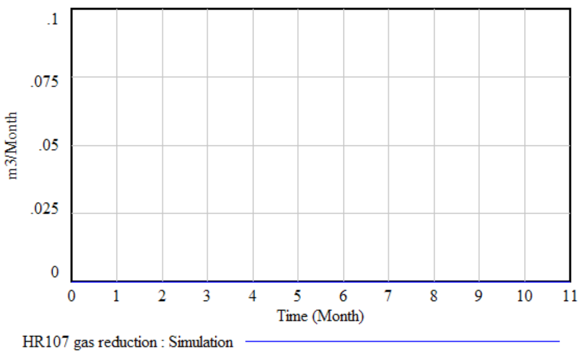


1.2 system optimization

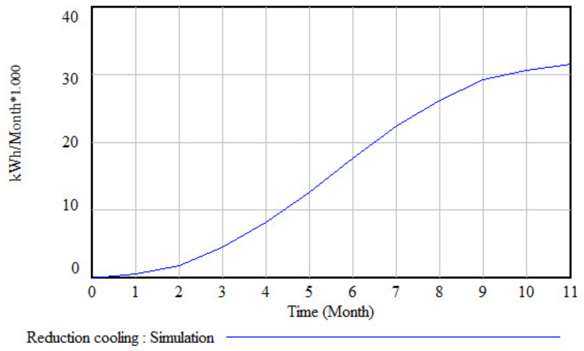
1.2.1 Demand controlled ventilation reduction



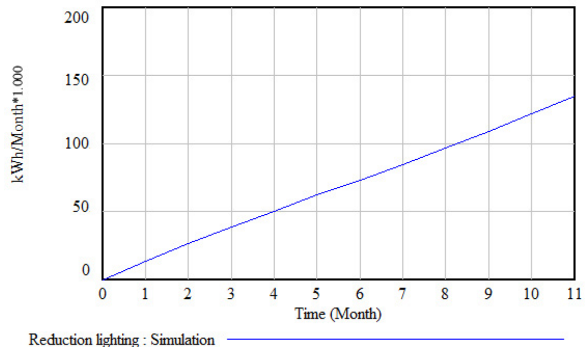
1.2.2 HR107 gas reduction



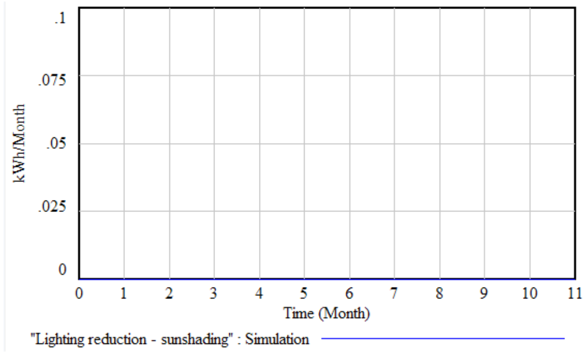
1.2.3 Reduction cooling



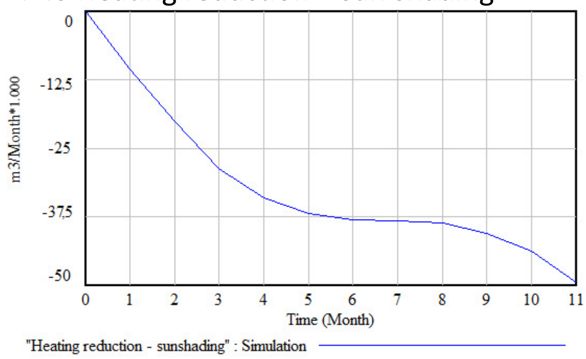
1.2.4 Reduction lighting



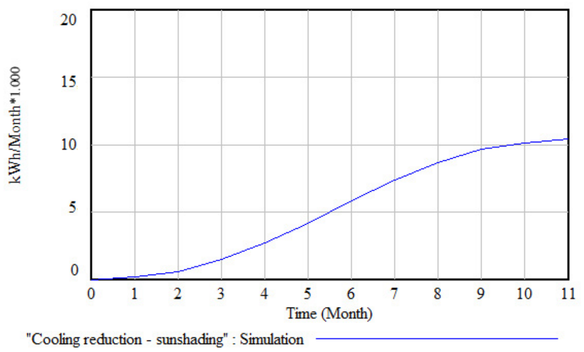
1.2.5 Lighting reduction – sun shading



1.2.6 Heating reduction – sun shading

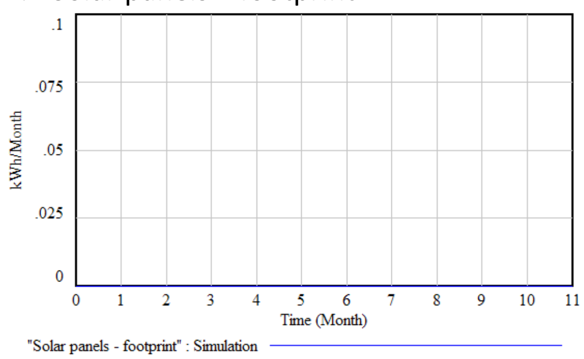


1.2.7 Cooling reduction – sun shading

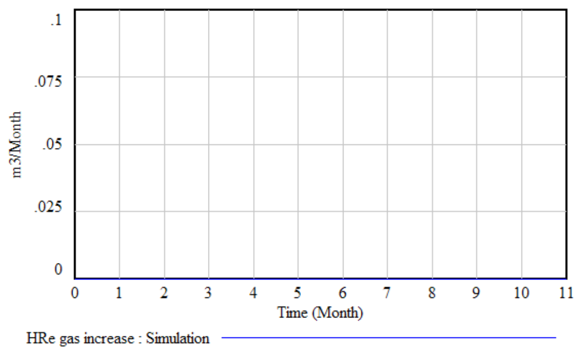


02 generation on building footprint

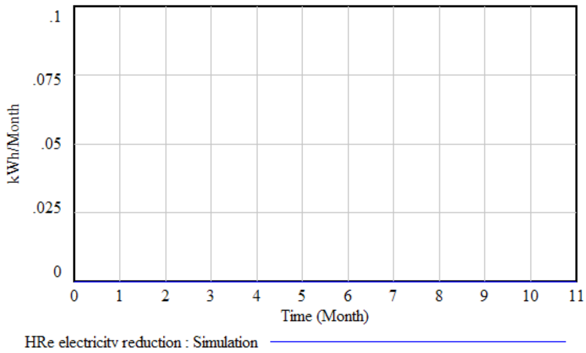
2.1 Solar panels – footprint



2.2 HRe gas increase

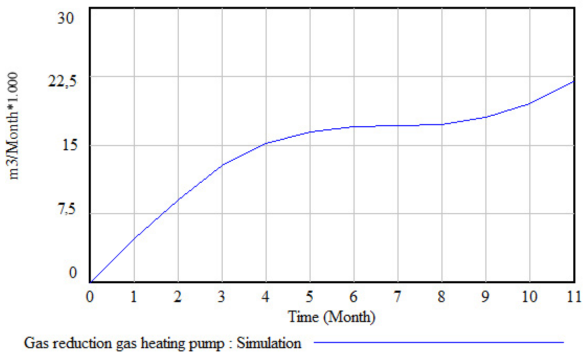


2.3 HRe electricity reduction

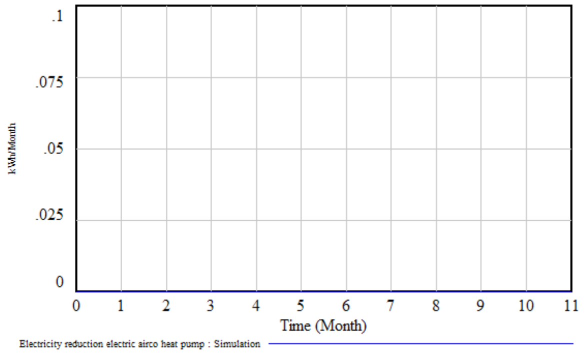


03 energy generation on-site

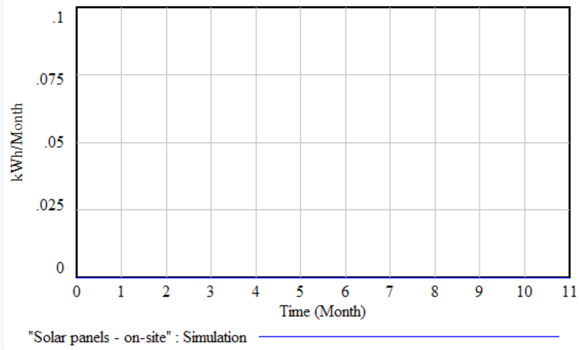
3.1 Gas reduction gas heating pump



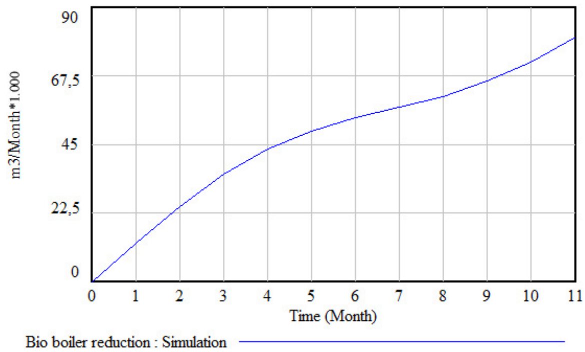
3.2 Electricity reduction electric airco heating pump



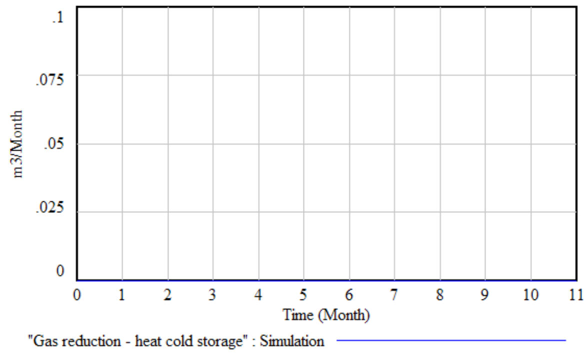
3.3 Solar panels – on-site



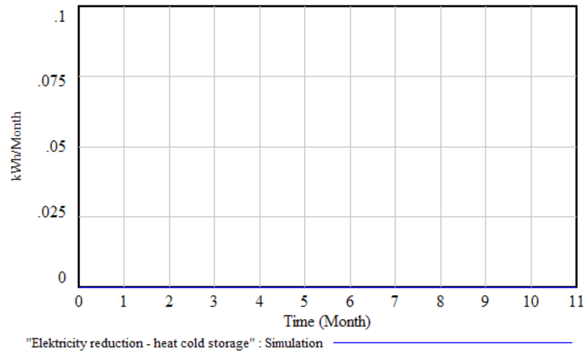
3.4 Bio boiler reduction



3.5 Gas reduction – heat cold storage

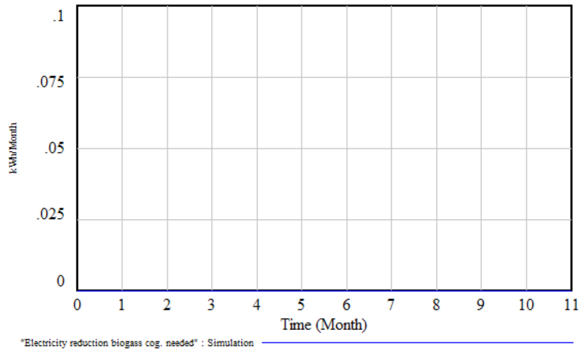


3.6 Electricity reduction – heat cold storage

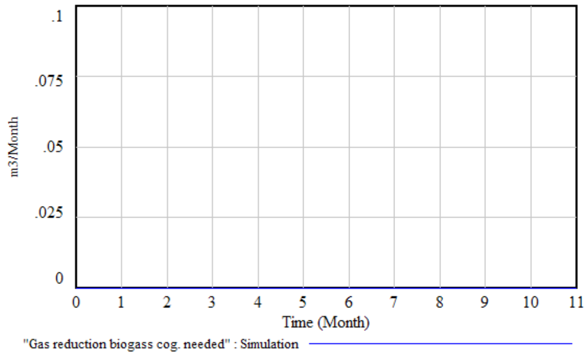


04 energy generation off-site

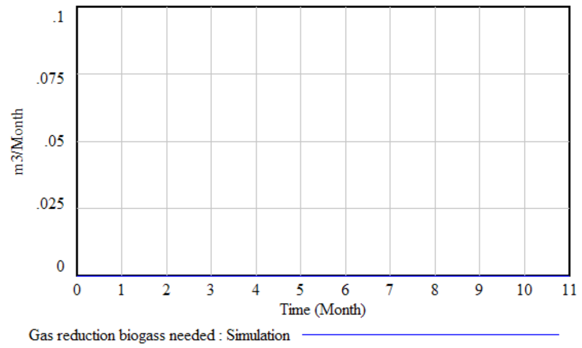
4.1 Electricity reduction biogas cog. needed



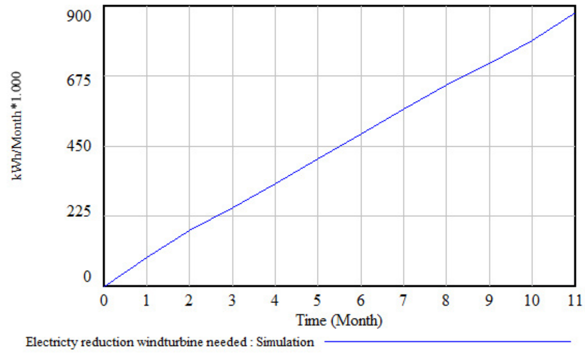
4.2 Gas reduction biogas cog. needed



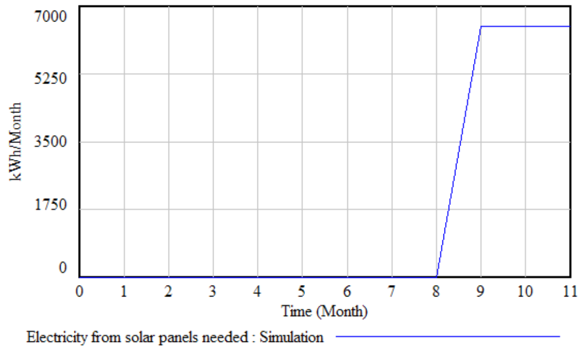
4.3 Gas reduction biogas needed



4.4 Electricity reduction wind turbine needed

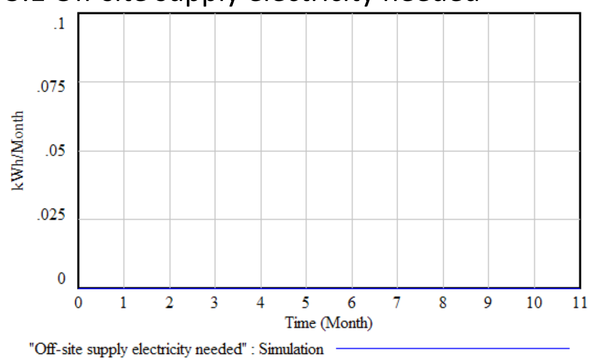


4.5 Electricity from solar panels needed



05 off-site supply

5.1 Off-site supply electricity needed



5.2 off-site supply gas needed