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Energy neutral neighbourhoods

Master thesis

Anna Hofgärtner

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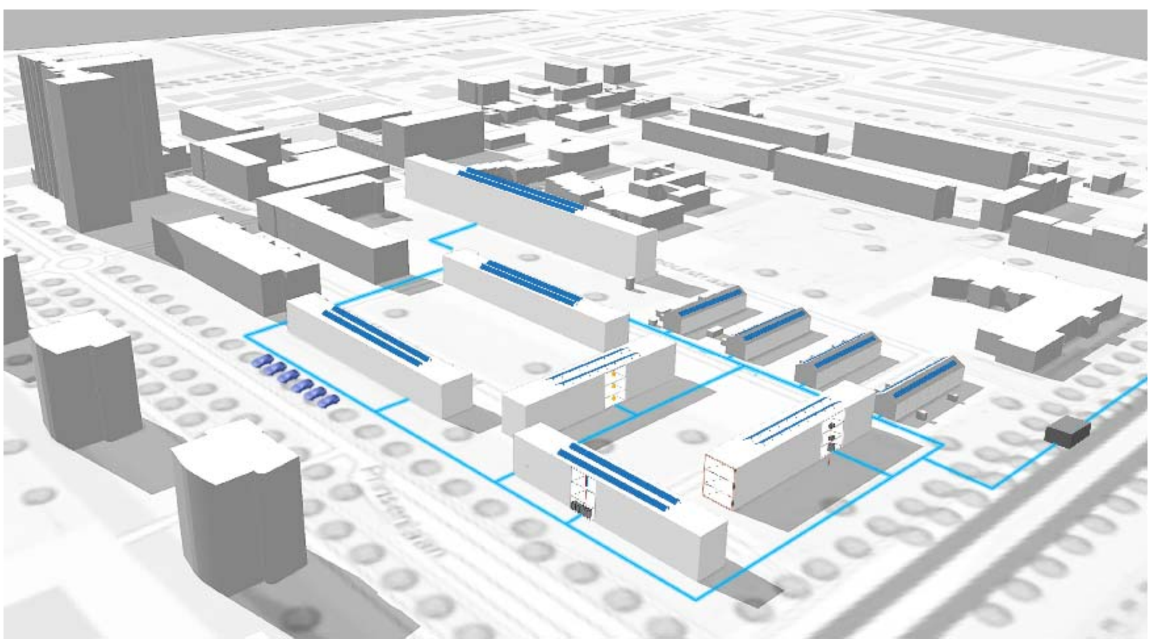

Energy neutral neighbourhoods

Master thesis

Anna Hofgärtner

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Committee:	Prof. dr. eng. P. Bauer	TU Delft, chair
	Prof. dr. ir. A. van Timmeren	TU Delft, university supervisor
	Dr. O. Isabella	TU Delft, external member
External supervisors:	Dr. O. Oung	Gemeente Rotterdam
	R. van Rooyen	Gemeente Rotterdam

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Abstract

English

The building sector accounts for 30% of the total energy consumption worldwide, which has a large potential for improvement in energy demand (OECD/IEA, 2015). In the Netherlands a large part of the building stock are existing houses and that eventually need to be transformed to become energy neutral. The scale of the neighbourhood makes it possible to bring inhabitants, the city and building level together. Not only electricity, heating and cooling demand is considered in this research, also transport is regarded as an important energy consumer of households. Energy demand can be reduced by improving energy performance of the buildings with measures such as insulation. Modern technologies such as electric vehicles and heat pumps, make it possible to move away from petrol and gas, which could decrease the annual energy demand significantly.

Most of the current electricity is centrally produced in a power plant. Energy from renewable sources can be produced on-site. Due to the intermittent character of local renewable energy generation, the stress on the grid could increase (Koch, Girard, & McKoen, 2012). Local grid problems can be prevented by introducing a microgrid (Ustun, Ozansoy, & Zayegh, 2011).

A microgrid makes it possible to match distributed energy generation with local demands. The electrification of technologies such as heat pumps and electric vehicles can cause increasing peak demands on the electricity grid. This will result in more interconnection between the heating, transport and electricity sector among other things.

Using an integral approach, the relationship between the built environment and energy sector was explored in this research. It was shown that the primary energy demand in the case study neighbourhood in Rotterdam could be reduced with 45% with measures such as strong insulation, heat pumps, solar panels and electric vehicles. In the worst case scenario this would lead to an increase in peak demand of 4.1 times the current situation. By improving the physical design variables in the built environment, this peak demand was reduced with 40%, which is 2.6 times the peak demand of the current situation.

Nederlands

Gebouwen gebruiken 30% van de totale energie wereldwijd. Dit heeft een grote potentie om energie te reduceren (OECD/IEA, 2015). Nieuwbouw maakt maar een klein deel uit van de totale woningvoorraad in Nederland. Een grote uitdaging is om de bestaande bouw energieneutraal te maken. Op buurtniveau kunnen bewoners en de schaal van de gebouwen en stad samen worden gebracht. Niet alleen elektriciteit, koeling en verwarming is meegenomen in het onderzoek; ook transport wordt gezien als belangrijk onderdeel van het energiegebruik van het huishouden. Energiegebruik kan worden gereduceerd door energieprestatie van gebouwen te verbeteren met maatregelen zoals isolatie. Moderne technologieën zoals elektrische auto's en warmtepompen maken het mogelijk om

onafhankelijk te worden van motorbrandstoffen en gas. Deze maatregelen kunnen het jaarlijkse primaire energieverbruik aanzienlijk verminderen.

Terwijl nu een groot deel van de elektriciteit centraal wordt opgewekt, kan duurzame energie lokaal worden opgewekt. Door de wisselende energieproductie van duurzame bronnen, kan het elektriciteitsnet onder druk komen te staan (Koch et al., 2012). Lokale problemen met het net kunnen worden voorkomen door het toepassen van een microgrid (Ustun et al., 2011). Op deze manier kan lokaal geproduceerde energie en vraag met elkaar worden uitgewisseld. De elektrificatie van technologieën zoals warmtepompen en elektrische voertuigen kunnen tot piekvragen van het elektriciteitsnet leiden. Hierdoor worden onder andere de warmte-, transport- en elektriciteitssector meer met elkaar verbonden.

Met behulp van een integrale aanpak is de relatie tussen de gebouwde omgeving en de energiesector onderzocht. In een case study buurt kon het primaire energieverbruik met 45% worden teruggebracht met maatregelen zoals sterke isolatie, warmtepompen, zonnepanelen en elektrische voertuigen. In het slechtste scenario kan dit tot een stijging van de piekvraag van 4.1 keer de huidige elektriciteitsvraag leiden. Met een verbetering in de fysieke ontwerpvariabelen van de gebouwde omgeving, kan deze piekvraag met 40% worden teruggebracht; dit is 2.6 keer de huidige piek vraag.

.

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List of symbols

ή	Efficiency	
$ή_{sys}$	overall efficiency system	
θ_i	Angel of incidence	°
θ_m	Tilt angle module	°
θ_L	local mean sidereal time	
λ_o	Longitude	° $(East = +, West = -)$
β	Longitude sun	°
λ_{pv}	Module temperature coefficient	$\%/°C$
ϕ_o	Latitude	° $(North = +, South = -)$
λ_s	Latitude sun	°
ρ_{water}	Density water	kg/m^3
ρ_{air}	Density air	kg/m^3
A_m	Azimuth module	°
A_s	Azimuth sun	°
a_m	Altitude module	°
a_s	Altitude sun	°
A	Area	m^2
COP	Coefficient of performance	-
E_{tot}	Total energy balance	kWh or MJ
E_{trans}	Transport energy balance	kWh or MJ
E_{elec}	Electricity energy balance	kWh or MJ
$E_{heat\&cool}$	Heating or cooling energy balance	kWh or MJ
$E_{elec,LP}$	Load profile electricity demand	kWh or MJ
$E_{elec,LP,impr}$	Improved load profile electricity demand	kWh or MJ
$E_{elec,HP}$	Electricity demand heat pump	kWh or MJ
$E_{elec,PV}$	Electricity production solar panels	kWh or MJ
$E_{elec,trans,EV}$	Electricity demand transport EV	kWh or MJ
C_{air}	Energy content air	$J/(K \cdot kg)$
C_{water}	Energy content water	$J/(K \cdot kg)$
ϵ	axial tilt of the earth	°
g_{glass}	solar heat gain coefficient	
$g_{shadefactor}$	shade factor	
I_{diff}	Diffuse irradiation	W/m^2
I_{dir}	Direct irradiation	W/m^2
I_{glob}	Global Horizontal Irradiation	W/m^2
I_{noct}	Irradiance under test conditions NOCT	W/m^2
I_{stc}	Irradiance under standard test conditions	W/m^2
hh	Household	
P_r	Rate power	W
$P_{out,tot}$	Power output from pv system ac	W
q_{heat}	Heating demand	kWh or MJ
q_{cool}	Cooling demand	kWh or MJ
$q_{balance}$	Heating balance	kWh or MJ
P_{trans}	heating demand for transmission	W

P_{infil}	heating demand for infiltration	W
P_{vent}	heating demand for ventilation	W
P_{intH}	heating from internal heat	W
P_{solarG}	heating from solar gain	W
$P_{in,htw}$	heat demand hot tap water demand	W
n	air change per hour	$1/h$
N	number of	
T_{amb}	Ambient Temperature	$°C$
T_{inside}	Temperature inside	$°C$
T_{in}	Temperature inlet	$°C$
T_{out}	Temperature outlet	$°C$
U	Heat transfer coefficient	$W/(m^2 \cdot K)$
V	Volume	m^3
V_{rate}	Volume air flow	m^3/s
d	Number of days	

Practical note

General structure

The main line of this research can be read in the summery at the end of each chapter. The theoretical part can be found in chapter 3 and 4, the practical part can be found in chapter 5 and 6.

Theoretical framework

The theoretical framework of this research is presented in Figure 1, which is based on the regulative cycle of Van Strien (Verschuren & Doorewaard, 1995). A theoretical and a practical part can be distinguished. The theoretical part stands for knowledge. Literature can be used as input for the problem definition. Studies that applied theory in practice for example in the form of a model, can be found in the overlapping part. The practical part, also named skills, involves the development of the model. Results can be compared to existing studies in the form of evaluation and function as new input for the model. Each part of the framework can be found in this research and is highlighted in the figure. The evaluation step happened throughout the report and is therefore not specifically associated with a specific chapter.

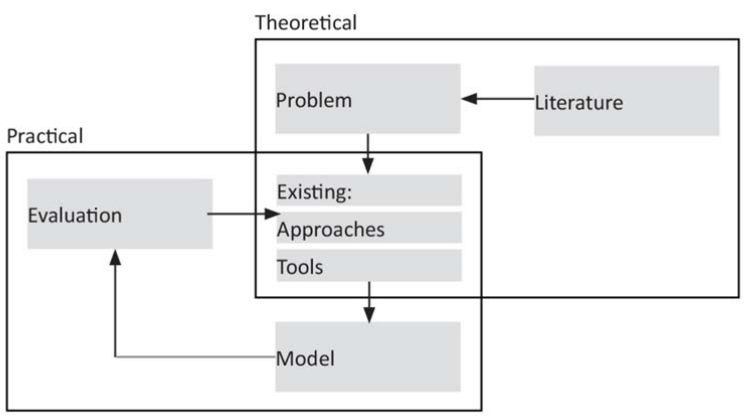

Figure 1 Theoretical framework concept

1 Introduction

1.1 Background

Background information can provide input for the problem definition. This is the theoretical part.

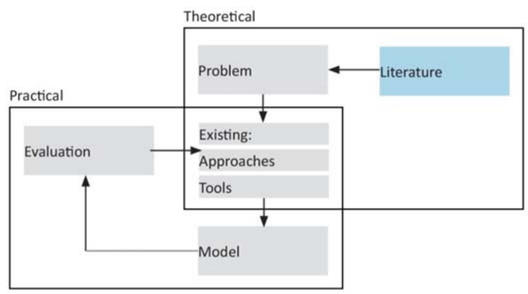

Figure 2 Theoretical framework literature

In order to mitigate global warming and to make the European economy more climate-friendly the EU set an ambitious goal to reduce energy consumption by cutting greenhouse gas emissions by 80-95% compared to 1990 levels by 2050 (European Commission, 2011). The building sector has a very significant role in this goal: in 2012 the built environment took up around 30% of the global energy consumption and half of the total electricity was consumed in buildings (UNEP, 2009). Even though improvements in energy efficiency have been stimulated, the energy consumption of buildings still increased with almost 20% since 2000 (OECD/IEA, 2015). Since households in Europe (EU 28) take up 24.8% of the total energy consumption (Eurostat, 2016). It is inevitable that can be concluded that the built environment has to be transformed in order to reduce energy demand dramatically.

The growing demand of the building sector in cities is due to the worldwide trend of urbanization: in 2010 half of the global population was living in cities and it is expected that this number will increase to 60% by 2030. This trend has two major consequences. Firstly, a large part of the energy demand is concentrated on a relative small area. Currently, about 60-80% of the energy is already consumed in cities. On the other hand, a high concentration of energy allows for a more efficient and cost-effective use (OECD, 2010, p. 17). This puts cities in the focus of reduction efforts.

While Dutch cities are also growing in population, in the Netherlands only a small portion of the housing stock is newly built. Figure 4 shows the newly built houses per year in comparison with the total building stock. This is less than 1 percent (CBS, 2017). Also, Figure 3 shows that only around 9% of the total building stock consists of houses built after 2005 and since a further decrease is expected in the coming years (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016). It can be concluded that the main challenge in the transition toward an energy neutral built environment by 2050, is primarily focused on the existing building stock.

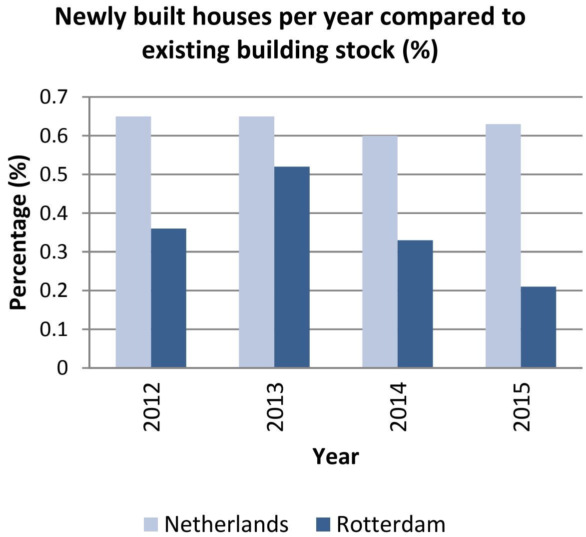

Figure 4 Newly built houses per year compared to existing building stock

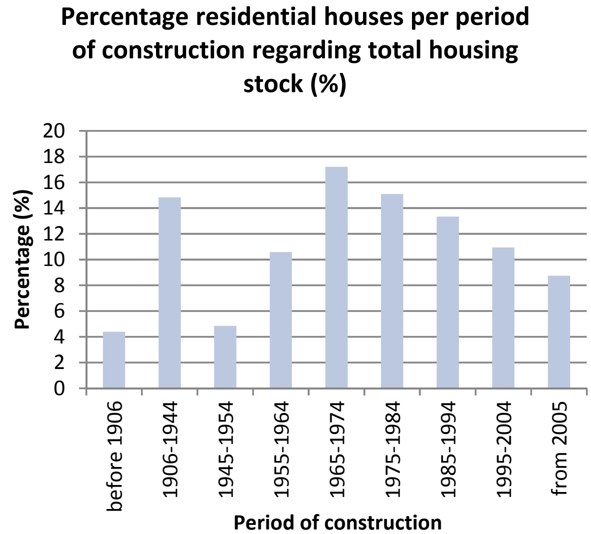

Figure 3 Percentage residential houses per period of construction regarding total housing stock

Another aspect of transforming the existing building sector is that the energy infrastructure of cities is very long lasting and challenging to adjust to meet the new requirements of an energy neutral built environment (Keirstead, Jennings, & Sivakumar, 2012). A crucial factor in energy efficiency is to increase the share of renewable resources. The European target for the Netherlands is set to produce 14% of its overall energy demand by renewable sources in 2020, a significant increase from 5.8% in 2015 (Ministerie van Economische Zaken, 2016). This goal puts households in the focus given that nearly 25% of the electricity demand in the Netherlands is consumed by households and the majority (85%) of them use gas for heating (Gerdes, Marbus, & Boelhouwer, 2016).

Whereas currently most electricity is produced centrally in a power plant, energy from renewable sources can be produced on-site by households. However, energy from renewable technologies such as solar panels, solar boilers or wind turbines, are in general dependent of local climate conditions such as sun, wind, outside temperatures (Koch et al., 2012) and therefore lead to intermittent production. Moreover, modern technologies such as electric vehicles and heat pumps, could further increase peak demand, while ICT increasingly supports the smart tuning of these. According to (Borg & Kelly, 2011) the peak demand in the European grid already increased with 1% between 2005 and 2008. On the other hand, the supply side could also stress the current grid when solar panels produce large amounts of electricity (Koch et al., 2012). Therefore new ways of matching demand with supply need to be found in order to integrate energy from renewable sources into the grid in an efficient way.

1.2 Problem definition

This chapter describes the problem definition, which is in the theoretical part.

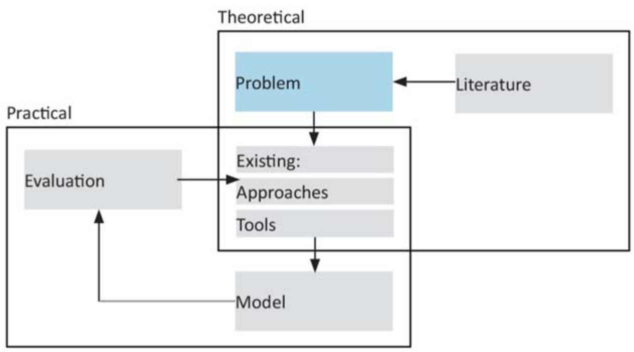

Figure 5 Theoretical framework problem definition

In order to reach the goals set by the EU the Dutch Government has the ambition to become energy neutral by 2050. The Netherlands is running behind compared to other countries of the EU (Energieoverheid, 2014): currently, only 5.8% of the energy is produced with a renewable source (Rijksoverheid, 2016)**.** This means that also the built environment in the Netherlands needs to become energy neutral by 2050. It is a huge challenge to transform the existing building stock to achieve this ambition. The role of cities is crucial and more responsibility is shifted from province level to municipality level. An existing neighbourhood in Rotterdam is used as case study in this research.
In this sub chapter is firstly described how the city of Rotterdam aims to realize this ambition. Secondly, the challenges of achieving an energy neutral built environment are illustrated.

The ambition of the municipality of Rotterdam is to produce more sustainable energy than the city consumes by 2030 for lower costs. One of the measures to achieve this is stimulating energy savings in the existing building stock. Also the current district heating network will be extended to eventually provide 150.000 households with heat. Additionally, wind turbines will be installed. Most of them will be located in the harbour, where the to be installed turbines will provide electricity for 200.000 households. Another ambition is to stimulate the installation of solar panels in order to reach a production of 20 GWh in 2018 and 1000 GWh per year by 2030. Finally, cleaner air is an ambition as well. To achieve this biking, use of public transport and electric vehicles will be stimulated (Gemeente Rotterdam, 2015).
At the moment still most of the houses in the Netherlands are heated with gas. It is a huge challenge to move away from gas and provide these buildings with a renewable heating source. This will require huge efforts to apply the Trias Energetica approach; achieve changes in the buildings to reduce energy demand and prepare them for the use of an alternative energy source, be it existing waste energy (exergetic principle) or renewables (Korbee, Smolders, Stofberg, & Vakgroep Landschapskunde en ekologie, 1980). The city Rotterdam developed with TU Delft (Van den Dobbelsteen & Tillie, 2011) the Rotterdam

Energy Approach and Planning (REAP) which is inspired on the Trias Energetica, but focusses more on exchanging energy and reuse waste streams.

Also electricity needs to be produced from a renewable source. The current electricity network is designed to supply the end user with electricity, which is centrally produced in a power plant. A change is needed in the electricity system to accommodate locally produced energy from, for example, solar panels. The current network is designed to be used in one direction; from source to end user. A local network, a microgrid, with the existing centralized grid as a backup, could solve this problem (Ustun et al., 2011). This allows matching the distributed energy generation with local demands.

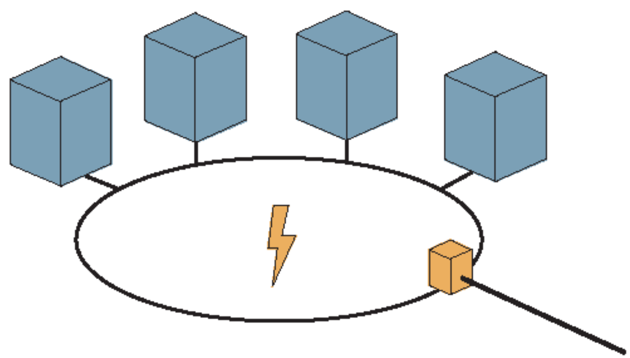

Figure 6 Concept microgrid

One way to improve the energy balance of the built environment is the electrification of technologies. For example, replacing cars on fossil fuel with electric vehicles or heating with a heat pump (Giezen, 2016).
Although these measures improve the annual energy demand of the city, they increase the electricity demand. This could lead to more fluctuations and peak demands in the electricity grid. As a consequence, high investments costs are needed to reinforce the electricity grid.
Therefore, a strong integration is needed of energy consumption, energy efficiency and energy production when planning a neighbourhood with a microgrid. This is in line with the Trias Energetica, mentioned before.
Designing a new energy system is becoming more complex and requires involvement of different disciplines; governments, building owners, architects, urbanists, inhabitants, grid operators, etc. In the transition towards an energy neutral built environment, the relation between the built environment and its energy profile becomes more important.

1.3 Goal research

The goal of this research is to determine how an existing neighbourhood could be transformed into an energy neutral neighbourhood by studying an existing neighbourhood located in Rotterdam. Also, how energy and the built environment are related with each other to determine the most influential factors.

1.4 Research questions

1.4.1 Main research question

How could the energy performance of an existing neighbourhood be improved to become energy neutral using a microgrid?

In order to answer this research question, a literature study was carried out first. This directed the approach of this challenge. Thereafter, a model was built to find the relationship between energy and the built environment. The outcome provides insight in how an existing neighbourhood could become energy neutral. This research was divided into five sub questions, shown below.

1.4.2 Sub questions

1 How is the energy neutral neighbourhood approached by different sectors?

Approaches in research towards energy neutral neighbourhoods are compared. Chapter 3 the differences and similarities area described based on various aspects such as aim, data, methodology, type of energy, level of detail, etc. Approaches towards microgrids, policy, building and urban scale are considered. Finally, it is shown how this leads to an integral approach.

2 How is an energy neutral neighbourhood modelled in existing tools?

An overview of currently available tools found in literature is presented in chapter 4. The selected tools differ in how an energy neutral neighbourhood is approached and modelled. The tools are compared with each other in aspects such as type of tool, goal of the tool, time step, time horizon, etc.

3 How could the different approaches be integrated into one model?

In chapter 5 is described how the findings from the literature study in the two previous chapters 3 and 4 are used for the model development. Creating an integral approach and serving the goal of the research are the two main requirements for the model.

4 How could the sub models of the main model be simplified?

This research integrates different sectors and requires various sub models. An overview of the sub models is given in chapter 6 Description model. It explains how the model is built and what simplifications are made.

5 How could this model be applied in an existing neighbourhood?

This model is developed together with a case study. Chapter 6 Description model presents how the specific information of the case study is used in the development of the model.

1.5 Challenge

There are two main challenges in this research. The first challenge is to combine approaches and methods developed and applied in the building sector and the energy sector into one integrated approach. The two sectors at first are not closely related because most of the energy is centrally produced and then distributed to the buildings. In an energy neutral built environment energy is produced more often decentralized and is as far as possible matched with the local energy demand and local storage. This means that the building and energy sector become more interconnected with each other in the transformation to an energy neutral neighbourhood.
Second, this research covers a large topic. Therefore, it is a challenge in the model building to find the right level of simplification of sub models. This means that the right balance has to be found between the level of complexity and the quality of the outcome.

1.6 Focus of research

The focus of this research is on measures that can be applied to an existing neighbourhood to improve its energy performance. It is important to notice that only energy is considered. Greenhouse gasses, financial and organizational aspects are not included. The scope of this research is on existing residential buildings. The outcomes could be used for a new neighbourhood, which is shortly described in chapter 9 Discussion; although this was not the key focus. Buildings with other functions than living have different energy profiles and are less suitable to apply the outcomes.

The ambition of the city of Rotterdam is to extend the district heating network and finally provide half of the buildings with waste heat from the harbour. As described in (Hofgärtner, 2016) there are also some drawbacks that need to be considered when rolling out a district heating network on such a large scale. Investing in this infrastructure will set the choice for heating for the next decades. Additionally, the business case could become uneconomical when heating demand of buildings will strongly be reduced by insulation.

An alternative approach is chosen in this research. Instead of rolling out a new infrastructure, the solution is searched closer to the buildings itself. At first heating demand is strongly reduced by insulation, three-layered glass and heat recovery ventilation. The remaining heating and cooling demand is provided by ground source heat pumps. An additional option could be to combine this with a solar boiler and seasonal storage in form of TCM. Solar panels are placed on the roofs to provide electricity. Finally, fuel cars are replaced by electric vehicles.

This vision is shared by Prof. Faaij (Oosterbaan, 2016). He states that it is essential to start looking further than only extending the district heating network since this could turn out to be an expensive infrastructure in the nearby future. His alternative includes similar measures as in this research: insulation, triple layered glass, solar boiler, solar panels and heat pumps.

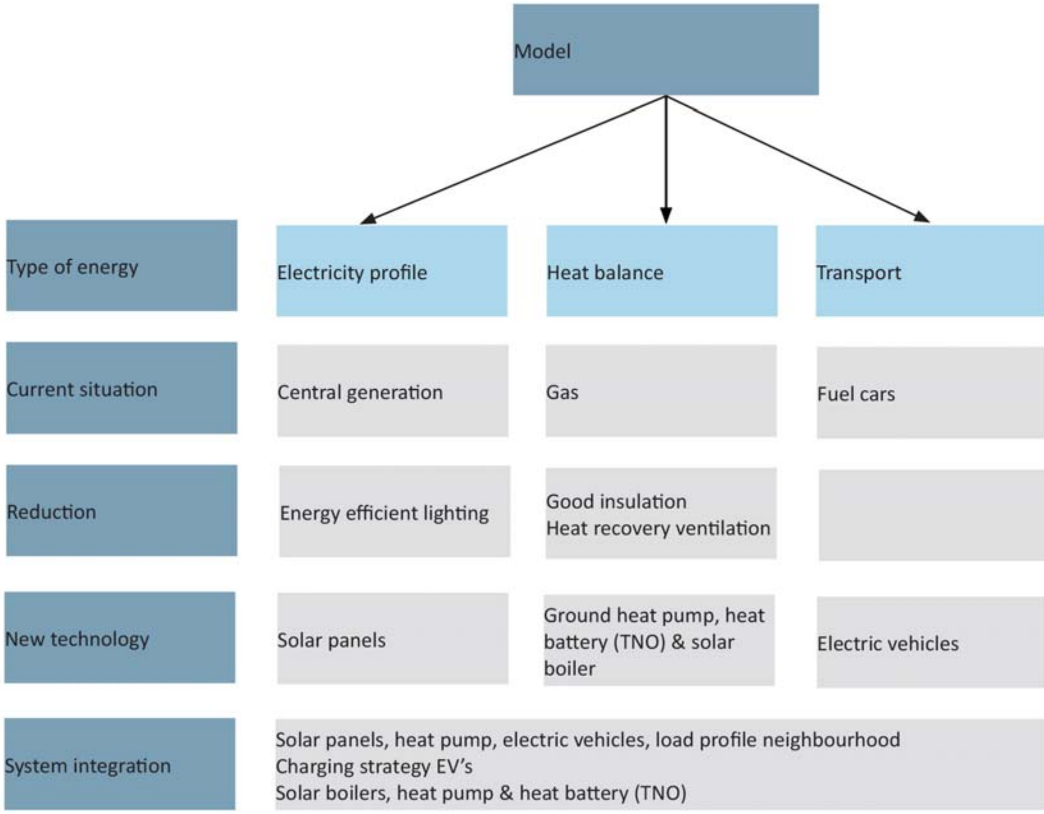

Figure 7 Overview research

This overview shows the setup of this research. The three main energy sources electricity, heating and transport are considered. The current situation can be improved by reducing energy demand. A next improvement is to replace the current technology with a new and renewable technology. Finally, these technologies can be integrated in such a way that peak demands are reduced. It has to be noticed that these are the steps taken in this research. Other steps that could be considered are re-using waste streams or efficient use of fossil fuels (Van den Dobbelsteen & Tillie, 2011). Also the shown improvements and technologies are not the only measures that could be applied, other possibilities are for example wind turbines, hydrogen cars or energy from biomass.

2 **Method**

The goal of this research is to find how an existing neighbourhood could become energy neutral. Therefore, it is important to study the relationship between energy consumption and the built environment. Firstly, a literature study is carried out consisting of two parts.

In the first part, different approaches in research are analysed to come to an integral approach. It was not possible to cover all sectors that are involved in energy neutral neighbourhoods. The approaches towards microgrids, policy, building and urban scale are described. It is compared how the topic “energy neutral neighbourhoods” is approached in research. Various aspects are used to assess the differences and similarities, such as: aim of research, methodology, use of data, level of detail, type of energy, etc. In this way an integral approach could be formed as base of this research.

The second part of the literature study concerns the analysis of currently existing tools that are used to model energy neutral neighbourhoods. This provides more insight about influencing factors when building a tool. For example the impact of the time step, time horizon, type of data, etc. on to be developed tool. Also different classifications of tools are compared; these vary in purpose of use and the final goal of research. This literature study provides input on how a model can be designed to serve the goal of this research.

The two parts are combined to build a model that has an integrated approach towards how an existing neighbourhood could become energy neutral. The model contains many topics. The challenge is to find the right level of simplification of the sub models.

The model is developed together with a case study neighbourhood in Rotterdam. This existing residential neighbourhood, built around 1965, is located in the district Prins-Alexander. The key challenge is to improve the energy performance of the buildings since this theme was limited included in the original design of the neighbourhood.
This way the model can be built according to the data and information that is available. On top of that, case study specific data can be used instead of general data. The different improvements are modelled to find how they influence the total annual energy balance and how they influence the electricity grid. Finally, different scenarios are compered. In this manner the relation between energy and the built environment can be found and with that the most influencing improvements can be determined.

3 Approaches

This chapter describes what researches have been carried out. These include a theoretical and practical part.

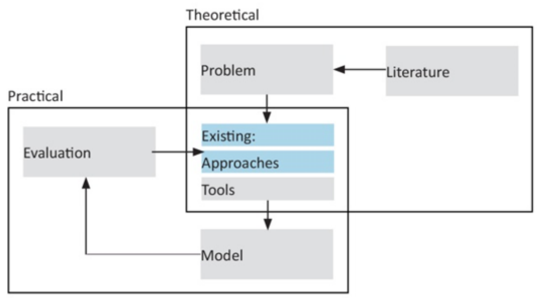

Figure 8 Theoretical framework existing approaches

3.1 Introduction

There are different ways to achieve an energy neutral neighbourhood. The approaches on four different levels are compared with each other. The considered focus areas are: microgrid, building and urban environment, and policy. As mentioned in the introduction, a multidisciplinary approach will be needed to come to an integral solution. The goal of this chapter is to compare the focus areas and find a way to integrate these into one approach. Table 1 provides an overview of the focus areas.

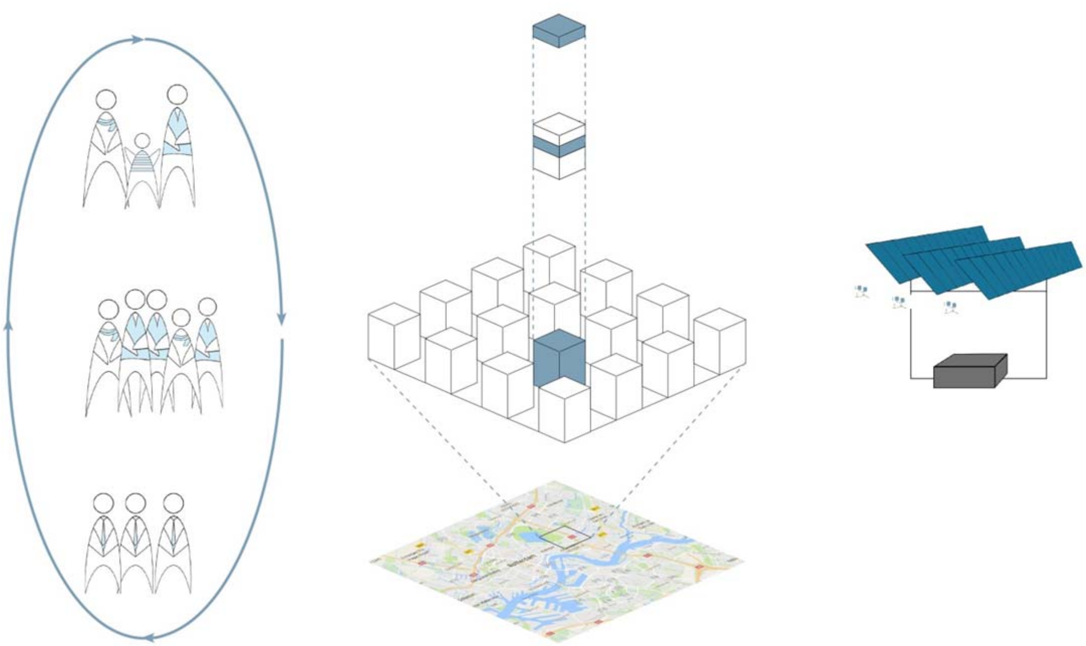

Figure 9 Different focus areas: policy, building and urban scale, microgrids

Focus area	Policy	Urban scale	Building scale	Microgrid
Object	Neighbourhood, City, Country.	Building block, Neighbourhood, City.	Building, Building block.	Components, Microgrid system.
Aim	Multi-disciplinary approach. Process & Support.	Min. energy demand. Optimise energy efficiency of urban structure. Re-use of available energy. Max. renewable energy production. Maximize energy efficiency of supply.	Min. energy demand. Max. renewable energy production. Efficient use of fossil sources.	Cost reduction. Increase of Flexibility, reliability & efficiency. Technical challenges.
Examples	Multi-objective optimization. Steering models. Bottom up/ top down. Ownership Feed-in tariffs	Morphology. Orientation. Dimensions buildings. Mixture of functions.	Orientation. Building shape. Organization of functions in building. R-values of insulation and glass.	Control strategies. Level of autonomy (grid vs storage). Plug & play concept. Inverter
Method	Case studies. Use of tools. Demand side Focussed.	Case studies. Use of tools. Demand side Focussed.	Case studies. Use of tools. Demand side Focussed.	Improvements operation and performance (modelling). Production side Focussed.
Data	Years - Decades.	Year.	Year.	Seconds - Hours.
Type of energy	Electricity. Heating. Cooling.	Electricity. Heating. Cooling. Transport. Metabolism (waste, water, etc.)	Electricity. Heating. Cooling. Embodied energy.	Electricity.

Table 1 Overview different focus areas

3.2 Policy

Object

The term community or neighbourhood is discussed differently in most of the assessed literature (Koch et al., 2012) and (Rae & Bradley, 2012), (Alexander Zhivov, 2014). Different definitions are found, for example, (Alexander Zhivov, 2014) makes a difference in physical, political or administrative boundaries. The reviewed articles do not only focus on the neighbourhood scale in a physical space. Also the process of achieving an energy neutral neighbourhood and the whole organizational structure are examples that are discussed. Additionally, the neighbourhood is placed in a larger context; it is related to larger scales such as city or country level or the influence of a certain technology. These aspects are part of this research.

Aim

Most of the studied literature about energy policies in the built environment, discusses how energy neutral neighbourhoods could be achieved in terms of process and roles of different stakeholders. In (Koch et al., 2012), (Rae & Bradley, 2012), (Zhivov, Case, Liesen, Kimman, & Broers, 2014) the importance is stressed to integrate different disciplines like social, technical, political and design, in order to come to a successful solution: a multi-disciplinary approach. There are many parties involved on different levels, each with a slightly different goal, which makes it a real challenge. An example to combine this is multi-objective optimization, which makes it possible to include different goals ranging from energy reduction to cost reduction, CO_2 reduction or the quality of design (Zhivov et al., 2014).
Secondly, the role of the government is widely discussed. This is a broad topic. This ranges from a top down and/or bottom up discussion to analysis of financial aspects, such as feed-in tariffs or ownership of an energy system in a community (Rae & Bradley, 2012) and (Koch et al., 2012).
An example is a steering model, (Zhivov et al., 2014) provides an overview of different types. This model could be used to find the role of different players, such as government or inhabitants, when developing an energy neutral neighbourhood.

Method

(Keirstead et al., 2012) found in their research that more than half of the papers are empirical studies, which means that lessons that come from practise are used as input. The other methods that were applied are simulation and optimization models to provide more insight what influence a policy measure could have. Also, most of the models used the demand side as a given input; just a small amount of studies included the interaction of demand and supply in the model.

Data

In general, the time horizon that is used by policy makers in the approach towards energy neutral cities concerns a period of years or decades (Keirstead, Jennings et al. 2012). A widely discussed topic is the importance of using a smaller time step such as an hour, since the installed capacity of renewable energy technologies increases (Koch et al., 2012).

Type of energy

Electricity is discussed in most cases in combination with heating and cooling (Koch et al., 2012) (Zhivov et al., 2014).

3.3 Urban scale

Object

The focus area of research is mainly performed on the scale from building blocks to neighbourhoods (Meijer, Adriaens, van der Linden, & Schik, 2011), (Holden & Norland, November 2005), (Marique & Reiter, 2014), (Ratti, Baker, & Steemers, 2005) to city scale (Butera, 2008).

Aim

Most of the analysed articles have the aim to reduce the energy demand in the neighbourhood, optimise the energy efficiency of the urban structure, re-use of available energy and maximize the energy efficiency of the energy supply.
It is frequently discussed what are the most influencing factors on energy demand in an urban area. Research is mainly focussed on the relationship between the physical buildings, space and the energy consumption. Important themes are: the form of the urban structure, the mixture of functions and transport.
The urban structure has influence on the energy demand of the buildings. Design variables such as morphology, orientation, the distance and height between the buildings, volume of the buildings have impact on local wind flows and the amount of sun and natural light entering the building (Butera, 2008).

The influence of the density of urban environments on heat losses, sun light and natural light in the buildings has been researched by (Steemers, 2003). It is stated by (Ratti et al., 2005) that the surface to volume ratio is not the only important factor. The proportion between passive and non-passive zones in a building has a significant impact on the energy demand. A passive zone is an area in the building that is naturally ventilated and lit.
Also the choice of materials, the amount of green and water can reduce heat in the city, which could reduce the demand for cooling. When minimizing energy demand is considered in an early stage of the urban design, it could lead to a higher energy efficient urban structure and cost reduction (Butera, 2008).
The density neighbourhood also influences the potentials for local renewable energy production. In highly dense areas the available space might be limited such that it cannot fulfil its local energy demand (Marique and Reiter 2014).

The mixture of functions in an urban area is another way to influence the energy consumption. Urban areas with a variety of functions will have a reduced peak demand because the functions have different demand profiles (Marique & Reiter, 2014) (Butera, 2008). Secondly, inhabitants need less travelling when various facilities, such as schools and shops, are present in their neighbourhood. This could reduce the energy consumption of transport (Butera, 2008).
Transport can be seen as part of the urban energy system. Besides of this environmental quality influences application of possible alternatives. For instance (Steemers, 2003) points out that for office buildings it is only possible to switch from air conditioning to natural ventilation when the air quality is high and the noise from the traffic is limited.

(Marique & Reiter, 2014) researched the impact of the urban form on the daily mobility. A framework is presented that can calculate the energy demand, local energy production and transport to integrate the different aspects of the urban energy system.
The relationship between daily mobility and the density of an area is researched by (Holden & Norland, November 2005). It was found that highly dense areas could lead to a lower energy demand for daily mobility.

Method

In most of the literature different case studies are compared to find a relation between the urban context and its energy efficiency. For example, three urban structures are analysed and compared by (Ratti et al., 2005): centre areas in London, Toulouse and Berlin. In (Marique & Reiter, 2014) an urban and a suburban residential neighbourhood are compared both located in Belgium. The study of (Holden & Norland, November 2005) 8 residential areas are considered. The researched articles by (Keirstead et al., 2012) show that also scenario tools were frequently used (in some case in combination with case studies). Here was the focus mainly on reduction of energy on the demand side; the supply side rarely played a big role.
By using a case study, it is possible to link an energy model with the actual energy demand. The energy demand of the built environment can be influenced by many factors such as user behaviour or social demographic backgrounds of inhabitants. Case studies could provide more insight in such factors, which might be difficult to include in a model.

Data

An annual energy balance of the neighbourhoods is presented by (Marique & Reiter, 2014). It was suggested to use a smaller time step than a year to show the differences between summer and winter. This is illustrated with an example on a monthly basis showing the fluctuations of the energy balances.
In the other articles, results are shown in energy consumption per year (Ratti et al., 2005) (Holden & Norland, November 2005) (Steemers, 2003). In some cases data with a smaller time step, such as a month or hour, was used as input.

Type of energy

Most of the research about energy in the urban environment included not only electricity but also heating and cooling (Ratti et al., 2005) and in some cases transport as well (Marique & Reiter, 2014) (Butera, 2008).
Also energy in a wider context has been considered for example in the form of waste (Butera, 2008). In (Meijer et al., 2011) even the whole metabolism of the city is considered including water, goods and food.

3.4 Building scale

Object

The considered articles focus on a single building (Sartori, Napolitano, & Voss, 2012) or on building block level (Georgiadou & Hacking, 2011). The interaction between a building (instead of a neighbourhood) and the energy grid is described in (Sartori et al., 2012). The development of energy performance of housing is researched by (Georgiadou & Hacking, 2011).

Aim

In general, the aim to achieve an energy neutral building is very comparable to the Trias Energetica; reduction of energy demand, production of energy by integrating renewable energy technologies in the building and efficient use of fossil fuel sources.
Decisions in the design of the building have a large influence on the energy demand, in particular the following factors: location, orientation, building shape, positioning of openings, natural light, shading, natural ventilation, organization of functions, R-values of insulation and glass and thermal mass.
(Georgiadou & Hacking, 2011) and (Sartori et al., 2012) make a distinction in the type of requirements that could be prescribed for buildings: prescriptive and performing. Prescriptive requirements are values that relate to the building itself such as U-values, air tightness or COP value of a system. Performing requirements are related to the energy demand and supply of the buildings.
(Georgiadou & Hacking, 2011) concluded that in most of studied cases the focus is on reducing greenhouse gas emissions by increasing energy efficiency and implementing renewable energy technologies. In general, energy efficiency did not play an important role in the design phase. The result is that most of the measures that were applied were standard practises such as light reduction, smart metering or improvements in insulation. Some demonstration projects used innovative improvements and applied a long term vision.
(Georgiadou & Hacking, 2011) suggests moving from a short term oriented to a more strategic vision. This could make the design more flexible for future developments. Examples are: taking into account the full life cycle of the building, applying new construction methods or implementing local energy systems.

Method

(Georgiadou & Hacking, 2011) researched 7 case studies (best-practices of European housing) to examine how future proof thinking is incorporated into the design. The research of (Sartori et al., 2012) is a framework of definitions, that is made by comparing different countries. This framework could be used when designing an energy neutral building. According to (Keirstead et al., 2012) most of the researches on building level are mainly focussed on reduction of energy demand instead of energy production.

Data

Often a yearly time step is used to calculate the energy balance of the building (Keirstead et al., 2012) (Sartori et al., 2012). The time that energy load matches with the production decreases each time step. For example, a building can be energy neutral on an annual basis. However, when considering the energy balance with a smaller time step, supply and demand are only matched during a part of the time. Therefore, a framework is presented to include the interaction between the building and the grid (Sartori et al., 2012). It was stated that in order to reduce peak loads a time step of one hour or smaller would be needed.

Type of energy

Electricity, cooling, heating and hot water demand are considered in the energy balance of the buildings (Keirstead et al., 2012). In some cases also embodied energy is included. This takes into account the energy demand of the whole lifecycle of a production for example the energy that is needed to produce building materials. Additionally new forms of energy could be taken into account such as electric vehicles (Sartori et al., 2012).

3.5 Microgrid

Object

The discussed objects reaches from components of a microgrid (Jiayi, Chuanwen, & Rong, 2008) to a more general focus on the energy system connected to loads and energy production technologies (Ustun et al., 2011) (Rae & Bradley, 2012). (Panwar et al., 2012) calls a microgrid an autonomous self-sustaining part of a power system. This includes locally produced energy that can be matched with local demand with help of a control strategy. A microgrid can operate simultaneously with the national grid, which can function as a backup system or it is implemented in an autonomous way combined with storage (Ustun et al., 2011).

Aim

Microgrids are not widely implemented in the built environment yet. The challenge is to connect a microgrid to the existing grid while being reliable and efficient (Ustun et al., 2011). Different aims were found in literature about microgrids: technical challenges, new control strategies, new business models and reduction of costs (Ustun et al., 2011) (Panwar et al., 2012) (Rae & Bradley, 2012) (Jiayi et al., 2008).

A technical challenge is the interaction of a microgrid the national grid, keeping the same power quality, reliability and stability. This means that the components also need to be suitable for a microgrid (Ustun et al., 2011). An example is an inverter. It needs a special control strategy to transform for example direct current from locally produced renewable technologies, into alternating current that is used by the national grid (Jiayi et al., 2008).
Additionally, new control strategies on a system level are required to match the varying character of renewable energy sources with the demand. This is a question that arises frequently in the assessed literature. (Panwar et al., 2012) suggests dispatching on a real time data due to the intermittent resources. Dispatching can be achieved using different constraints or objectives such as costs, CO_2 emissions, level of autonomy.
Demand side management could make the energy system more efficient. It is easier to match demand with supply and the storage capacity can be reduced. It also makes the system more flexible for example when the demand changes when more houses are added (Rae & Bradley, 2012).

Another challenge is cost reduction of a microgrid. This new system is not widely implemented yet and is still expensive in comparison to the alternative: the national grid. When introducing a microgrid in an existing environment, the microgrid is added on top of the national grid, which makes it even more important to reduce the costs.
(Jiayi et al., 2008) points out that because mainly customized systems are applied that the costs are still high. Also is the flexibility of the system is low since there is lack of plug and play methods. (Ustun et al., 2011) suggests to make a systematically, universal standard which could make implementation very easy and reduce the costs.
Also new forms of business models are needed with the growing number of prosumers. This requires a different way of auctioning energy than with a single grid operator. For example,

auctioning the energy could happen on different levels, requiring a new control strategy (Jiayi et al., 2008).

Method

Since the development of microgrids is not mature yet, most of the assessed researches focused on problems that needed to overcome first before it is a concept ready for implementation on a larger scale. Most studies on a system level were mainly focussing on optimization, for example matching demand with supply with a cost reducing objective. One of the goals is to find operation patterns and gain more insight in how much investments are needed (Keirstead et al., 2012).

(Jiayi et al., 2008) provides an overview of the different type of dispatching methods that could be applied. Also practical researches were carried out. (Panwar et al., 2012) explains how a microgrid could be brought into practice on a small scale with a limited number of buildings and loads.

Other papers zoom in on smaller scales such as different components of a microgrid and how they could be improved to increase efficiency and reliability (Jiayi et al., 2008). For single technologies simulation was mostly used or in some cases experimental setup (Keirstead et al., 2012).

(Rae & Bradley, 2012) points out the potential of demand side management; however, the main focus was of the articles were on supply side; demand was considered as a fact and used as input value (Keirstead et al., 2012).

Data

The time step that is used depends on whether only one technology is considered or an entire system. This is ranging from seconds for electric vehicles to hours of solar systems in the articles reviewed by (Keirstead et al., 2012). A time step of an hour (Jiayi et al., 2008) or even 15 seconds (Panwar et al., 2012) was used to dispatch energy. Another suggestion was to use real time data in future (Rae & Bradley, 2012),(Ustun et al., 2011).

Type of energy

The researches with the focus on microgrids, consider mainly electricity. In some cases, this is combined with heating solutions such as CHP.

3.6 Integral approach

In order to come to an integral approach, the previously described points of view are compared and discussed.

Object

The research on microgrids was not specifically linked to a physical scale where the microgrid was applied. In some articles the focus was on smaller parts of the microgrid, such as components, in others the interaction with the national grid was described.
The building and urban scale are closely related with each other and show some overlap on the scale of building blocks. The considered articles about urban scale included a large range from building blocks to neighbourhoods and city scale. The policy oriented articles had even a broader scope; from neighbourhood to city or even country level. This scale is not only limited by the physical environment. Here, also the administrative or financial context is taken into account.

Aim

Since the microgrid is not widely applied yet as a new system parallel to the national grid, the focus mostly is on problems that need to be overcome before it can be implemented. Examples are cost reduction, control strategies, increase of flexibility and technical challenges.
Research applied on building and urban scale is mainly focussing on the design variables to achieve reduction of energy demand, increase of energy efficiency and provide local energy production. The aim of the focus area policy is in particular on the process and support of realizing an energy neutral neighbourhood. The role of the government and the use of a multi-disciplinary approach can are widely discussed topics.

The main focus in the approach towards microgrids is primarily on the production side, while the building and urban scale have their main scope on reduction of energy demand. Both perspectives can be combined in a more integrate approach to achieve an energy demand profile which is also advantageous for the microgrid, in terms of peak reduction or costs. A multi-disciplinary approach can be achieved by coupling the built environment with the microgrid.

Method

Various improvements in operation and performance are discussed in the approach towards microgrids, such as control strategies. On building and urban scale often case studies are used as input. Many articles on policy related aspects are based on real practises. These methods could be combined. First, the energy performance of a neighbourhood can be modelled to find the influence of improvements. Second, actual energy demand profiles of a case study can be used to link the model with.

In general, all considered focus areas use models to estimate the impact or compare different options. These are not considered in this chapter. An overview of currently available tools is presented in chapter 4.

Data

Small time steps were commonly used in the focus on microgrids, in general ranging from seconds to hours. A larger time step was applied in the focus area of the built environment; annual energy balances were mostly used, which was in some cases based on more detailed data. The articles from a policy point of view considered the energy neutral neighbourhood on a wider time span ranging from a year to decades.
Although in the focus areas policy, urban and building scale, the time step was significant larger than the approach towards microgrids, the importance to include a smaller time step in future work was pointed out in these articles. It could show the interaction between the buildings and the grid and to what extend the neighbourhood is energy neutral when seasonal, monthly and daily fluctuations are included.

Type of energy

Electricity is the main focus with respect to microgrids. However on a building level, the energy balance investigated except for electricity, also hot tap water and supply for the heating and cooling demand. Sometimes the embodied energy was considered as well.
On an urban scale transport related energy was also included. In some of the articles energy was even considered in a wider context where also waste, water, food and goods were taken into account. In literature about policies mostly only electricity, cooling and heating demand was named.
Overall, all points of view include electricity. Heating and cooling demand are important for the energy balances on building and urban scale and are mostly related to the dimensions of the buildings. Also mobility patterns are repeatedly linked with the building density on an urban level.
When heat pumps and electrical vehicles are adopted, this could influence the electricity demand on building level and the grid. This shows that heating, cooling, transport and electricity could become more interconnected with each. The assessed articles about microgrids consider various loads of the built environment but not often are these loads linked with the spatial dimensions of the built environment. Therefore, supply and demand could be combined in an integral approach. The electricity demand profile could be linked with the physical variables of the built environment.

3.7 Summary

Different focus areas and points of view towards energy neutral neighbourhoods were considered in this chapter consisting of: policy, urban scale, building scale and microgrids. A comparison was made based on the object of research, the aim, the method, data and type of energy.

Heating, cooling and transport become more interconnected with electricity when heat pumps and electric vehicles are introduced. The energy demand of heat pumps and electric vehicles is related to the physical built environment. When linking the variables of the buildings with their electricity demand on the grid, matching of demand and supply could be improved. In this way, peak demands could be reduced which could reduce the overall system costs.

A neighbourhood could be energy neutral on a yearly basis, but when a smaller time steps are considered it could mean that demand and supply is only matched a part of the time due to the seasonal, monthly and daily fluctuations. A smaller time step, such as an hour, could be used to make the inclusion of the fluctuations of renewables and new loads such as heat pumps and electric vehicles more feasible.

In this way the different aims can be combined in an integral approach. The improvements that can be made in the physical neighbourhood to become energy neutral could be linked with its electricity profile. By using a smaller time step, the matching demand and supply could be improved leading to reduction of peak demands.

4 Existing tools

In this chapter is described what existing tools have been developed. This includes a theoretical and a practical part.

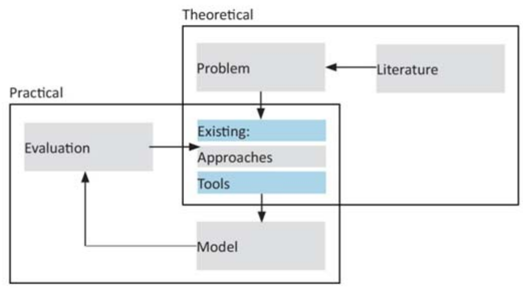

Figure 10 Theoretical framework existing tools

Many tools are developed to model (renewable) energy systems. The tools vary in the different aspects that are taken into account such as: time step, detail, complexity, objective, purpose and type of technologies. This chapter provides an overview of 12 currently available tools. These tools are compared on how the energy system is approached and how it is modelled. The goal is to find the influence of the various aspects on a model and on its outcome. Firstly, the influences of different aspects are described. Secondly, the type of tools and its purpose are compared.

4.1 Introduction

Implementing renewable energy technologies in cities could lead to a reduction of grid transmission losses and congestion problems. Modelling energy systems in the urban environment is becoming even more important because of this. The insights provided by these models give an important indication of the possibilities of generating renewable energy in the city and on how this can be integrated in the existing urban energy systems (Allegrini et al., 2015).

Time and space become essential factors in the development of energy tools due to the intermittent character of renewable energy technologies and the increasing local energy generation. The focus is not only on the production side; also the possibilities of flexible demand are included (Pfenninger, Hawkes, & Keirstead, 2014).

For this research the following tools are analysed: CitySim, DEECO, Effort, EnergyPLAN, EnergyPlus, H2RES, HOMER (Energy), Inforse, LEAP, MARKAL/TIMES, RETScreen and TRNSYS. Specific details can be found in annex A.

General

Accuracy, complexity and scale are aspects that are interconnected with each other. It depends on the aim of the tool and to what level of detail these characteristics are modelled (Allegrini et al., 2015).
When exploring different options in an early stage of a project, a simplified model could be very useful (Allegrini et al., 2015). (Pfenninger et al., 2014) point out that the benefit of a simplified model is that many runs can be made for, for example, a detailed uncertainty and sensitivity analysis. Another advantage of using a simple predictive model, is that the user will not only focus on the outcome of the model but place the outcome in a wider perspective. Examples of other important aspects are politics, social impact and practical limitations (Klosterman, 2012). However, very simple models could rely heavily on assumptions. The outcome could provide a solution which is not representative for the situation (Keirstead et al., 2012).

A complex model includes detailed processes and relationships of the different variables. This could provide precise information about for instance the energy production of a system. The disadvantage is that it takes more time to run such a model (Keirstead et al., 2012), (Pfenninger et al., 2014). A drawback of a complex model is that it is hard for users to judge the limitations of the model (Klosterman, 2012).

With the upcoming intermittent resources, a smaller time step and detailed demand profiles are needed (Pfenninger et al., 2014). For the development of the national grid, it becomes more important to use detailed models on a small scale. It makes it very complicated since this involves scales ranging from a couple of metre to a few kilometres. The challenge here is to find the suitable level of detail (Robinson et al., 2009).
Besides different scales, an integrative approach is needed in energy modelling. Nevertheless it is not always desirable to model an integrative approach when a detailed outcome is required, which could make the model too complex (Allegrini et al., 2015).

On option is to link a simplified model to more detailed models. Depending on the aim of using the model, a simplified or an extensive version could be used (Allegrini et al., 2015), (Robinson et al., 2009). This allows to link different scales in a model. For example, when installing solar panels on the roof of a building, the inhabitants might only be interested in how much this could reduce their yearly electricity bill. A simplified model would be sufficient. A grid operator would need a more complicated model to estimate the moments of peak production for the sizing of the electricity grid.

Another solution would be to use a complex model simultaneously with a simplified model to verify the outcomes. For example, there are many tools available that describe the operation of a certain technology. When aiming to make a model on a higher level the operation times of the technologies can be simplified. This could be validated with more detailed models (Allegrini et al., 2015). An example is that the simplified model could be used to estimate the yearly energy production of solar panels. An extensive model could give a more detailed overview of the hourly operation of the system and validate the outcomes given in the simplified model.

Type of use

In most of literature in which tools were compared and assessed, a classification of tools was made. The analysed tools are presented in Table 2 together with their type of use. The type of use can be one or more of the following: scenarios, accounting, simulation, investment, or operation optimization.

An accounting tool provides insight in parameters and quantities of a certain system or technology such as energy production, energy efficiency, costs or emissions (Manfren, Caputo, & Costa, 2011).
Scenarios can be compared in a scenario tool, which is in general oriented on the long term with a time horizon ranging from 20 until 50 years and a time step of one year (Connolly, Lund, Mathiesen, & Leahy, 2010). An example of such a tool is Inforse. It balances the energy system on a national level taking into account: energy production and consumption, trends and policies. This tool is used to make different scenarios for a time horizon up to 100 years (Connolly et al., 2010). Scenarios can also be made to compare different situations from an operational perspective for a short period such as one year.

A simulation tool is used to model the dynamic character of the system or technology according to (Manfren et al., 2011). By simulating the system, the tool can be used to make a forecast and is therefore a predictive tool (Pfenninger et al., 2014). It is mostly used for a short term analysis of one year with time steps of an hour (Connolly et al., 2010).

Optimization can be seen as a technique, with the aim to provide scenarios compared to the current situation or to specific defined situation (Pfenninger et al., 2014). There are two main types of optimization tools, with different objectives. One is used to optimize the costs and the other is used to optimize the operation of the system (Connolly et al., 2010). An upcoming technique is multi-objective optimization that combines different objectives that might be conflicting. An optimization tool is used to find the best solution with several constraints and variables. A constraint could be for example the limited capacity of a certain technology or maximum allowable CO2 emissions.
For most of the energy systems optimization models use a mathematical calculation method to balance supply and demand. This can be done by LP (linear programme), MILP (mixed integer linear programme) or a NLP (non-linear programme). (Allegrini et al., 2015)

The following table, Table 2, provides an overview of the reviewed energy tools, including a short functional description and categorization for the typical type of use.

Name tool	Description	Type of use
CitySim	Support tool for sustainable urban planning. Simulation of energy flows in buildings. It is planned to extend this with embodied energy, flows of water and waste and urban climate	simulation
DEECO	The Dynamic Energy, Emissions and Cost Optimization tool is used for modelling energy systems to assess the costs versus sustainable improvements	simulation, (investment & operation) optimization
Effort	Support tool for sustainable development neighbourhoods. Uses indicators for building, architecture, mobility, ecology, resources	simulation, scenarios
EnergyPLAN	Entire energy system is simulated to provide insight in planning strategies on regional and national level	(investment & operation) optimization, simulation, scenario
EnergyPlus	Building simulation model including heat balance of buildings and building systems	simulation, (operational) optimization
H2RES	This balancing tool can be used to stimulate the integration of renewables in stand-alone energy system, such as islands	(operation) optimization, simulation, scenario
HOMER	Simulation and optimization of energy systems	simulation, (investment & operation) optimization
Inforse	Simulation of national energy system by using energy balances	scenario
LEAP	Long-range Energy Alternatives Planning is used for analyses of the national energy systems	accounting, simulation, scenario
MARKAL/TIMES	This general model can be used to assess scenarios over a long time period	(investment) optimization, scenario
RETScreen	This tool can be used to make decisions by comparing different scenarios	accounting, (investment) optimization, scenario
TRNSYS	This tool can simulate transient systems. A complex energy problem can be divided into small models.	simulation, (operation) optimization, scenario

Table 2 Overview reviewed energy tools

Approach

Two types of approaches can be distinguished: a top down approach and a bottom up approach. According to (Connolly et al., 2010) a top down approach can help for example in predicting energy prices or demand on a macro economical level in the long term. Mostly, historical data are used which is in general easily available. This method is simple and can include economic and social effects. Drawbacks are that it is not very detailed so it does not provide any information on individual level. (Swan & Ugursal, 2009)
A bottom up tool is more focussed on different technologies, its investments and alternatives (Connolly et al., 2010). These tools make use of data on the level of the individual or a small group. This can be extrapolated to a higher level to make the data representative for a bigger group (Swan & Ugursal, 2009). Bottom up tools are in general more complex to model and need more detailed data. This could be: climate, building properties or technology properties. By simulation the qualities can be determined and this is a good approach to model new technologies.
(Swan & Ugursal, 2009) state that with the upcoming renewable energy technologies a bottom up approach would be more applicable since the focus is more on individual demand profiles and on local energy production.
In the Effort tool the neighbourhood is regarded as a layer to bring the policy perspective and the inhabitants perspective together by combining the top down and bottom up approach (Roselt et al., 2015).

The overview in Table 3 shows whether the tools use a bottom up or top down approach.

	Approach	Data
CitySim		sensitivity*
DEECO		
Effort	bottom up, top down	
EnergyPLAN	bottom up	sensitivity
EnergyPlus		partial sensitivity
H2RES	bottom up	
HOMER	bottom up	sensitivity
Inforse		
LEAP	bottom up, top down	database, sensitivity
MARKAL/TIMES	partial bottom up, top down	
RETScreen	bottom up	database, sensitivity
TRNSYS	bottom up	partial sensitivity

Table 3 Approach and data use of tools

*It is planned to add this to the tool in future

Data

A complex model requires typically input with a certain level of detail. Sometimes it can be hard to acquire the right data. Two problems with data can be identified: availability and uncertainty. It can be hard to understand how the input and output relate to each other when using a complex model. Another complex part is to understand how assumptions

influence the outcome and to what extent conclusions can be drawn from a complex model (Keirstead et al., 2012).
(Pfenninger et al., 2014) describe two ways of dealing with uncertain data. The first method is varying the input data many times to examine how this influences the outcomes. The second method described is using stochastic inputs that are taking into account in the decisions. An example of a tool that has an extensive sensitivity analysis is HOMER according to (Mendes, Ioakimidis, & Ferrão, 2011). Other tools that include a sensitivity analysis are shown in Table 3.
(Robinson et al., 2009) suggest to model energy demand with a stochastic model to incorporate the unpredictability of the users' behaviour. Acquiring demand data are crucial when designing and sizing a system, but hard to predict since it depends on many factors such as weather, population or building performance (Huang, Yu, Peng, & Zhao, 2015).

Another new field of information that could be integrated in energy models is location specific data such as GIS. This becomes more important for tools that focus on energy planning on district level because it influences the efficiency of the system and the capacity that can be installed (Allegrini et al., 2015). It is a new way to link with the urban texture. Except for mapping the potential of distributed energy generation, also energy consumption and other environmental aspects could be included. For example, it can be used to add a constraint in the design for air pollution (Manfren et al., 2011).

Some tools are connected to a database. The importance of a database is growing in order to base the model on realistic numbers. It can provide more insight in efficiencies, energy production of technologies and systems or in environmental calculations (Manfren et al., 2011). After all, a database is a snapshot of the technologies available at that moment and does not include predictions or developments. This fact needs to be taken into account when using such a database as input for a model.

Time step, time horizon & scale

The choice of the timescale depends on the type and the scale of the project that is modelled and the reasons of using the tool. A time step of (micro)seconds could be used for a very detailed simulation, while a time step of a year is more suitable for a more policy driven goal. Also the time horizon has a large scope; this can range from a day to decades. The time step, time horizon and the scale of each tool is presented in Table 4.

The tools can be divided in roughly two groups: operational and planning tools (Pfenninger et al., 2014).
More traditional planning tools such as LEAP are based on in and outgoing streams. The LEAP tool is applied to projects on a large scale; an example of this is the national energy system. This tool is used for analyses on the long term of about 20-50 years and uses a time step of one year (Connolly et al., 2010).
A load duration curve is used as input; the electricity demand of one year is divided into a couple of time slices. The energy production is matched with each time slice. This integral energy balancing method is simple and does not require detailed data. However, it does not take the varying character of renewables into account. This could result in a simplification of the capacity factors and the energy balancing. This could lead to an underestimation of the actual use of the energy that is produced by renewables and it could result in an underestimation of CO2 emissions. (Haydt, Leal, Pina, & Silva, 2011). This makes this type of tool not suitable to use it for setting energy targets, energy management, analyses (including demand side) of a distributed renewable energy systems (Huang et al., 2015).

While the operational side played a small role in traditional energy models, it becomes more important due to the constant variation of energy generation from renewable technologies (Pfenninger et al., 2014). Therefore, a smaller time step than one year would be necessary.
In most cases, the scale of the project decreases as well.
Tools such as CitySim (Robinson et al., 2009) and H2RES (Connolly et al., 2010) operate at this level. An hourly time step is used to model an energy system on the scale of neighbourhood or island. This time step allows optimizing for example the integration of renewables in the energy system.
The tools TRNSYS and HOMER can model even on a smaller time step. TRNSYS can be used for detailed modelling, using a time step varying from 0.01 seconds to one hour (Connolly et al., 2010). It can simulate heat or electricity profiles of a specific technology in a building. This makes it less suitable to perform energy calculations on a larger scale such as city or district level (Allegrini et al., 2015)

When including the varying energy production of renewables, two types of modelling can be used: semi-dynamic or dynamic modelling.
A system can be modelled using a couple of representative periods such as week and weekend days in different seasons on an hourly basis. This is called semi-dynamic and can be applied in the tool TIMES.
Dynamic modelling is used for a period ranging from one day to a few years with a time resolution of one hour or smaller. Tools such as EnergyPlan and HOMER use this type of modelling. A disadvantage is that detailed data is required, which is not always available (Haydt et al., 2011).

In conclusion, the choice for a type of tool depends on the purpose. For a long term scenario planning, tools such as Inforse, RETScreen and LEAP are suitable. When the goal is to include the fluctuations of renewables, tools like EnergyPLAN or HOMER are a better choice (Connolly et al., 2010) (Mendes et al., 2011).

	Time horizon	Time step	Scale
CitySim	1 year	hourly	Neighbourhood - city
DEECO		Hourly	Large scale distribution generation system
Effort	-	-	Neighbourhood
EnergyPLAN	1 year	Hourly	Regional – national energy system
EnergyPlus		Hourly	Building – urban district
H2RES	unlimited	Hourly	Stand-alone energy system, island
HOMER	1 year	minutes	stand-along or grid connected energy systems
Inforse	50-100 years	yearly	National energy system
LEAP	No limit (30-50 years)	yearly	National energy system
MARKAL/TIMES	20-50 years	Hourly – monthly	Energy system on community to global level
RETScreen	Max. 50 years	monthly	Different scales energy systems individual to global scale
TRNSYS	Multiple years	0.01 seconds - hourly	Energy systems at building level

Table 4 Time horizon, step and scale tools

Content

The content of the model such as energy, costs, etc. also relates to the scale of the tool. On a larger scale more different topics can be included, while on a smaller scale normally the focus is on a single aspect.
H2RES is a tool that focusses only on energy; in particular the integration of renewable energy technologies in the system. No economic aspects are taken into account (Mendes et al., 2011).
Though most of the models shown in Table 5 include technical and economic aspects, also a form of environmental facet is included, for example expressed in kg CO2 emissions.
Just a limited amount of models consider social aspects (Mendes et al., 2011). One reason for this could be that economic and technical aspects are quantitative (Pfenninger et al., 2014). Social aspects such as user behaviour, public acceptance and the complexity of implementing are harder to model. However, these factors could be a significant part of uncertainty in a project.
The tool CitySim (Robinson et al., 2009) includes a form of user behaviour. It is explained that the presence of inhabitants in the building has influence on the heat balance and electricity demand for example by opening a window or turning on the TV. This user behaviour could be modelled with a probability profile of the presence of an inhabitant in a building.

	Energy (heating and/or electricity)	Transport	Economic	Environmental	Social & soft factors
CitySim	x	x	*	*	-
DEECO	x	-	x	x	-
Effort	x	x	x	x	x
EnergyPLAN	x	x	x	x	-
EnergyPlus	x	-	x	x	-
H2RES	x	partly	-	-	-
HOMER	x	-	x	x	-
Inforse	x	x	x	x	-
LEAP	x	x	x	x	-
MARKAL/TIMES	x	x	x	x	-
RETScreen	x	-	x	x	-
TRNSYS	x	-	-	-	-

Table 5 Type of energy in tools

*It is planned to add this to the tool in future

(Keirstead et al., 2012) state that a limited number of models integrate different disciplines or sectors. One of the tools that use an interdisciplinary approach is the Effort tool, which can be used for redeveloping an energy efficient neighbourhood. Not only energy is considered but also more general sustainable aspects such as mobility, building culture, city image or ecological functionality. These are rated with indicators in terms of social, economic and environmental sustainability (Roselt et al., 2015).

Another example is the tool CitySim. Besides energy flows it is planned to extend this model with embodied energy, water and waste flows as well (Robinson et al., 2009).

Some models include the transport sector as well, besides thermal energy and electricity of buildings. In most cases, these are the tools that consider a larger context. This could be in terms of scale (Inforse, LEAP, MARKAL/TIMES) or in content (CitySim, Effort).
The fact that the tool TRNSYS does not considers transport, can be explained by the fact that it is a detailed model focussing on one type of technology and not related to a bigger context (Allegrini et al., 2015).

Further research fields

According to (Allegrini et al., 2015), there is a lack of models that integrate different activities such as dimensioning, designing, control, planning, operation on different levels. Therefore, it would be interesting to optimize urban planning by integration of system analysis, physicals aspects of the site and simulations on building level.
(Keirstead et al., 2012) state that not often is described what the perfect model would be. Model makers should be aware what the goal of the tool is and show how the energy system is interconnected with for example urban policies.

There are just a limited number of tools that make use of energy indicators. This could be useful for planners in the design phase to have an indication to what extent energy goals have been reached when making an detailed urban plan (Huang et al., 2015). The indicator provides feedback to the user to what extend the initial goal has been reached. For example, the renewable energy production reached 70% of the goal that has been set before.

One widely discussed issue is demand side management and its potential in the future. New technologies such as smart meters make it possible to provide more insight in this field.
Data about the demand side can be obtained via smart meters. Smart meters can provide real time electricity data of every household. This can give more information about the time and the size of the energy demand. (Pfenninger et al., 2014). (Keirstead et al., 2012) suggest using activity based models to simulate the demand side.

4.2 Summary

In this chapter, important aspects of energy system simulation tools are described. These are: level of complexity, scale, time step, time horizon, content and dealing with data. The choice for each of these aspects depends on the purpose of the application. In general, the tools include not only energy, but also economic and environment aspects. Transport is not widely implemented.

A one hour time step is needed to cover the fluctuations of intermittent resources. Most of the operational tools simulate the energy systems with a time horizon of one year. A bottom up approach is more suitable for a neighbourhood level since local data are needed to match demand with supply of a distributed renewable energy production. This can also be combined with top down when policy is included as well. Using an hourly time step and the input of local parameters, the required data is very detailed. This could result in a complex model including uncertainties. Using a sensitivity analysis can provide more insight in the relationship between parameters and their influence of assumptions.

5 Model development

5.1 General

The goal of this research is to find out how an existing neighbourhood can become energy neutral. This includes heating, electricity and transport by cars. Modern technologies that could improve the energy balance of a neighbourhood, such as heat pumps, solar panels or electric cars influence the electricity grid (demand and production) in a neighbourhood. By improving the energy profile of the neighbourhood, extreme peaks in the electricity consumption can be prevented. The objective is to minimize the net electricity demand (energy production – demand). This model is simulated with a time step of one hour and a time horizon of one year. In this chapter aspects are described that are important requirements for the model to be developed.

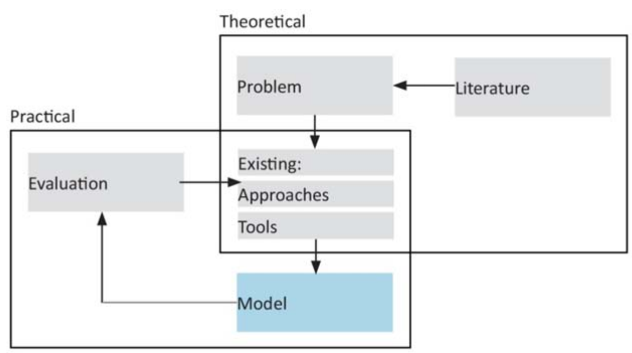

Figure 11 Theoretical framework model

Goal of model

In chapter 3 different approaches towards energy neutral neighbourhoods were discussed. Three main steps can be distinguished from these approaches: These happen in different phases, on different levels of detail and have different goals.

The scheme shows that the planning of a neighbourhood has influence on the design of the building, the design of a building has influence on the operation of the energy system. The goal of this model is to relate the different fields and combine planning, design and operation in order to come to an integral approach.

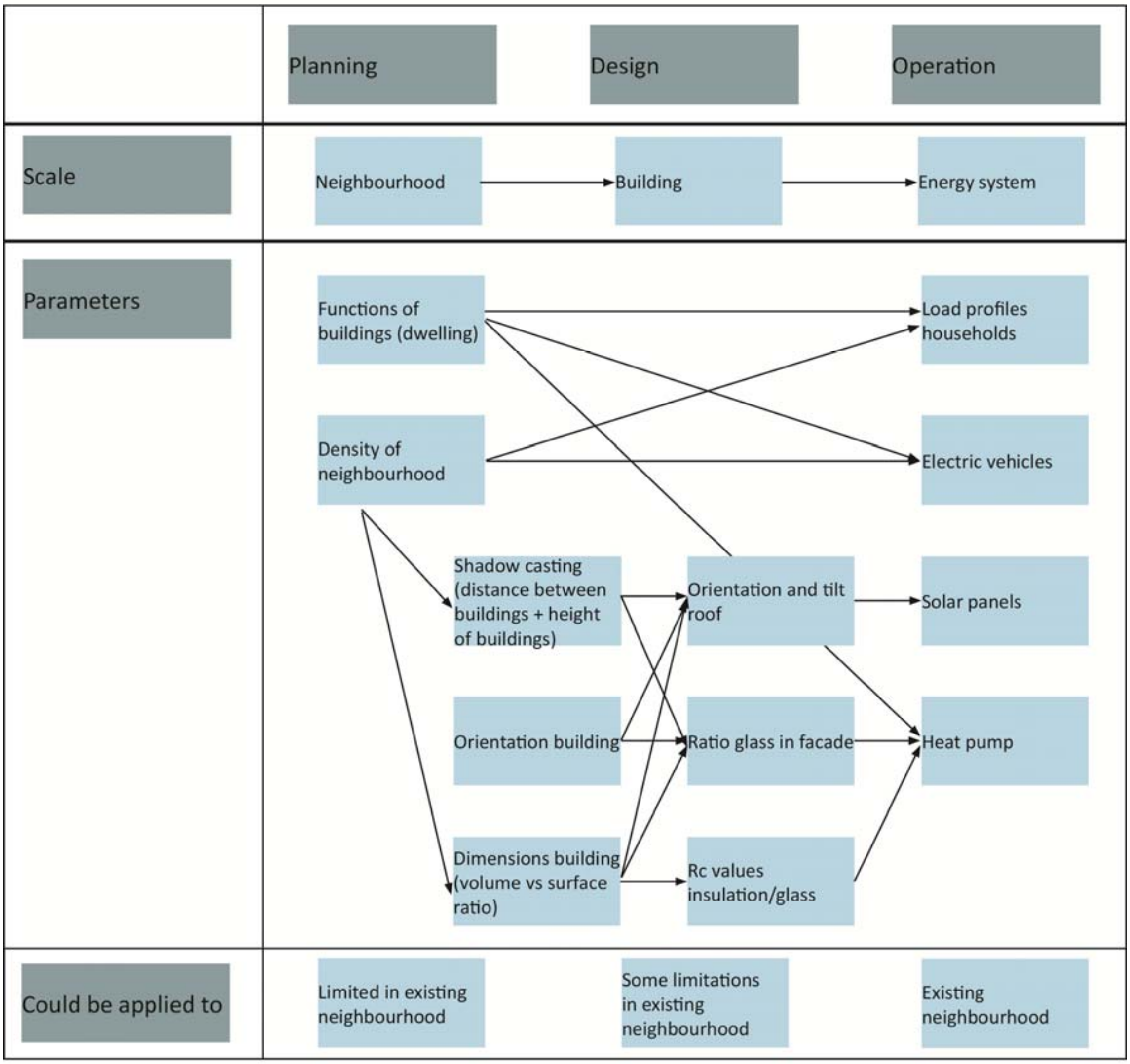

Figure 12 Influence of planning, design and operation

In this way, the energy system is not added in the last phase, but integrated in the planning and design of the neighbourhood. If the energy balance of a neighbourhood or building is included in an early stage, this could prevent peak loads in the operation stage and could result in better matching between supply and demand. In this way the needed storage capacity and reinforcements of the electricity grid can be limited.

Type of model

In chapter 4 different type of tools are described, such as accounting, simulation, scenario and optimization models. The choice for a type of tool depends on the goal of the research.
A scenario tool is mostly used for modelling the influences of policy measures or penetration of a technology in the market. The main focus is on process or development, in general with a time horizon of couple of decades and a yearly time step.
According to (Manfren et al., 2011) an accounting tool provides information; it is used to estimate parameters and to calculate quantities, resulting in one single outcome. If a certain

measure would be applied in a neighbourhood, such as installing solar panels, it would show how much the energy production would increase. It could show the relation between n applied measure and the influence on the energy balance.
The same applies to a simulation tool, that is used to predict or describe the behaviour of a dynamic technology or system. This type of tool provides information rather than improving the energy system or urban design.
An optimization tool could be used to find the optimal set of adjustments and technologies to let a neighbourhood become energy neutral. A combination of the previously described tools is also an option, for example a simulation – optimization tool. In this tool the outcomes of the simulation model are compared and then used to optimize. The outcome of the optimization is used as input for the simulation model again.

The aim of this research is to find the relationship between the built environment and the energy performance with as goal to discover how the neighbourhood could become energy neutral. Therefore, a scenario model is chosen to compare the combinations of improvements. From the scenarios, the best option could be selected.

In contrary to an optimization model, this will provide information about the relationships between the possible implementations and the energy performance of the built environment instead of reaching one optimal and final outcome. The insights that have been gained in this research, could be used in further research to carry out an optimization study including investment and operational costs. This is out of scope of this research.

Time horizon

The focus of this research is on the energy profile in the current situation and the improved situation. It is not about the transition or process towards the improved situation, which means that the time horizon does need to cover several years or decades. A time horizon of one year covers the main fluctuations that are important for the sizing of a new energy system such as day, night, winter, summer, weekdays, weekends and rush hours.

Time step

Chapters 3 and 4 show that in various approaches and tools different time steps are used to match energy demand with supply. The applied time steps range from a yearly time step to a time step of a (micro)second.

If the yearly energy production is equal to the yearly energy consumption, this neighbourhood could be called energy neutral. When a smaller time step is considered, it might turn out that the supply is only matched partially with energy demand due to seasonal or daily fluctuations. For example, solar panels could produce enough electricity on a yearly basis to supply the annual electricity demand of a household. Nevertheless, it produces most of its energy during the day and in summer which could lead to a shortage in supply in the night or winter (Koch et al., 2012).

This means that the term “energy neutral” is closely related to the time step. In general, in energy neutral planning and design of a neighbourhood a time step of a year or month is used, while minutes or even microseconds are used in the calculations of the operation of the energy system. To overcome this problem, a time step has to be found that could “communicate” with both; planning, design and operation.

When choosing a time step, it is important that it is detailed enough to cover the critical periods of mismatching the loads with the energy production of renewable technologies that have an intermittent character. This mismatch could occur during the seasons, day and night, working day and weekend, the varying temperature outside, the varying insolation of the sun and rush hours.

An hourly time step seems to cover all those fluctuations. If a smaller time step would be considered such as 5 minutes, the data that needs to be processed is extensively more. The question rises whether such a detailed outcome would lead to more accurate design of a neighbourhood while some unforeseen or unplannable changes, for example user behaviour, would have more significant influence on the energy balance.

Scope of research

The energy demand in a neighbourhood can be divided into three categories: electricity, heating & cooling and transport.

In the transition from fossil fuel based technologies to renewable energy technologies, an electrification of technologies in other sectors can be seen. For example, from diesel or petrol cars to electric vehicles in the transport sector or gas heaters to heat pumps for heating & cooling sector of building. It has to be noticed that electrification is not the only possible option to a renewable fuel. Hydrogen could be an alternative for the transport sector, the same applies for a district heating network in the heating sector.

The focus of this research is not on predicting the uptake of technologies in the next decades, but on the influence on the electricity grid of measures that can be applied in a neighbourhood to make it energy neutral. It is a challenge to match these new loads such as electric vehicles and heat pumps, with the intermittent character of solar panels. This can be improved by modifying the buildings. For example peaks caused by heat pumps could be reduced by insulating the building well.

By combining planning, design and operation an integral approach can be achieved. The direct approach of policy makers is limited included since their focus is more process orientated. However, the outcomes of this model could be used by policy makers to gain more insight. This could help in the choice for stimulating certain technologies or measures and preventing grid congestion problems.
The focus of the model is on the possible improvements that can be taken in a neighbourhood. This means that heavy industries or large scale wind turbines are not included since it is not likely to have them in an urban context.

Many tools, that were analysed in chapter 4, use investments and running costs as constraint or objective function (minimizing costs). This research is primarily motivated by energy rather than economics. The insights gained in this research about relations between energy and the built environment could be used in further research to find the cost effective ways to achieve this.

Finally, the user dependent factors are not the scope of this research. For instance, the interaction between the user and the technology. These could be important issues for further research, eventually based on the outcome of this research.

Applicability

The model will be applied to an existing neighbourhood. The outcomes and relations that are found could also be used to plan a new neighbourhood. The main difference between a new and an existing neighbourhood is the possible measures that can be applied. In an existing neighbourhood, the current buildings need to be adjusted while in a new neighbourhood it can be designed from scratch. Especially on an urban scale the possible adjustments are limited in an existing neighbourhood. It is hard to make radical changes is orientation or size of the buildings. Also on building level, the possible modifications can be constrained due to monumental status, the building structure or preservation of the character of the district. Although there are constraints in a new still to be build neighbourhood as well, like maximum building height, there is more freedom in planning and designing a neighbourhood in such a way that its morphology supports a low energy and high potential to produce energy sustainably. In conclusion, the model requires a multi input of all parameters of a neighbourhood and making it possible to leave some input variable fixed or variable depending on the constraints.

5.2 Most determent factors

In (Gerdes et al., 2016) is stated that the energy consumption of households (excluding transport) is more than 20% of the total electricity and gas consumption in the Netherlands. In order to know what the most effective measures are to reduce the energy demand of the residential sector, an overview is presented of the energy breakdown of Dutch households.

Current situation

The yearly energy use of households is shown in the Table 6 for the years 2000 and 2015, consisting of electricity, gas and fuel for cars.

Energy breakdown household (Gerdes et al., 2016)		
Year	2000	2015
Average number of persons per household	2.3	2.2
Gas demand per household [m3]	1900	1432
Electricity demand per household [kWh]	3103	2966
Fuel for car per household [l]	1067	964

Table 6 Energy breakdown per household

The annual electricity consumption increased until 2005, this slowed down afterwards and started even decreasing after 2012 due to more energy efficient appliances and lighting (Gerdes et al., 2016).

Gas consumption is much lower in 2015 in comparison with 2000; the result of improvements in insulation and efficiency of gas boilers. Fuel used for cars contain the average tanked litres fuel (diesel, petrol, LNG) for passenger cars and company cars. Although more distance in covered on average per car, the fuel consumption has decreased as well because of more efficient vehicles. This energy break down considers the direct energy use only, which means that the energy that is needed for, for example food production or flights is excluded (Gerdes et al., 2016).

Alternative heating fuels such as coal, wood or district heating accounted only 3% of the total residential energy consumption in 2014, which is around 3 GJ. Most of the Dutch households (85%) have central heating on gas (Gerdes et al., 2016). This is the highest number in Europe (B Asare-Bediako, Ribeiro, & Kling, 2012).

If a gas combination kettle (combi-HR) is used, 80% of the energy is used for room heating and 20% for hot tap water (Gerdes et al., 2016). Only 1.5% of the residential buildings used a heat pump in 2015; mostly in newly built houses. Although it is a small percentage, the number of installed heat pumps increases with 30% per year.

In order to compare the energy demand of gas, electricity and fuels, they are converted into MJ. The following conversions factors are used (Gerdes et al., 2016).
1 m3 gas (standard) = 31.65 MJ/m3
1 kWh electricity (primary energy, conversion factor 2.24 or efficiency of 44.6%) = 8.064 MJ/kWh

1 kWh electricity energy content = 3.6 MJ/ kWh
1 Litre of fuel (for car, weighted average diesel, LPG & petrol) = 34.5 MJ/litre

This gives the following energy balance.

Year	2000	2015
Gas demand per household [GJ]	60.1	45.3
Electricity demand per household [GJ]	25.0	23.9
Fuel for car per household [GJ]	33.8	30.5
Total [GJ]	118.9	99.8

Table 7 Energy breakdown per household (GJ)

Table 7 shows that gas accounts for most of the energy consumption. Transport by car is almost one third of the total energy consumption of households.
The energy demand heavenly varies from neighbourhood to neighbourhood. Gas and electricity consumption by households is widely distributed and is dependent on number of persons per household, size of the building, appliances, insulation and behaviour (Gerdes et al., 2016). For example, 20% of the households use less than 1000 m3 gas, while almost 17% uses more than 2400 m3 gas. This is similar for electricity; about 10% of the households use less than 1500 kWh per year while 14% uses more than 5500 kWh (Milieucentraal, 2016c).

The gas consumption depends for example on the type of building; a free standing house has an average annual gas consumption of 2440 m3, while an apartment uses less than half (1060 m3 gas) (Milieucentraal, 2016c). Also the year of construction is an influencing factor. A building from before 1946 has an average yearly gas use of 1980 m3, in contrary for houses built after 2000 this is only 1410 m3 gas (Milieucentraal, 2016c). The number of persons in a household has huge impact on the electricity demand. A single person household uses on average 2420 kWh per year, whereas a house with five persons requires on average double the electricity demand. Although the total electricity demand per household is higher with more inhabitants, the average electricity consumption per person is much lower due to sharing of appliances, like lighting, dishwasher or oven (Milieucentraal, 2016c).

Having a closer look at the electricity consumption; the table shows the appliances that are the largest consumers with lighting as number one (Gerdes et al., 2016).

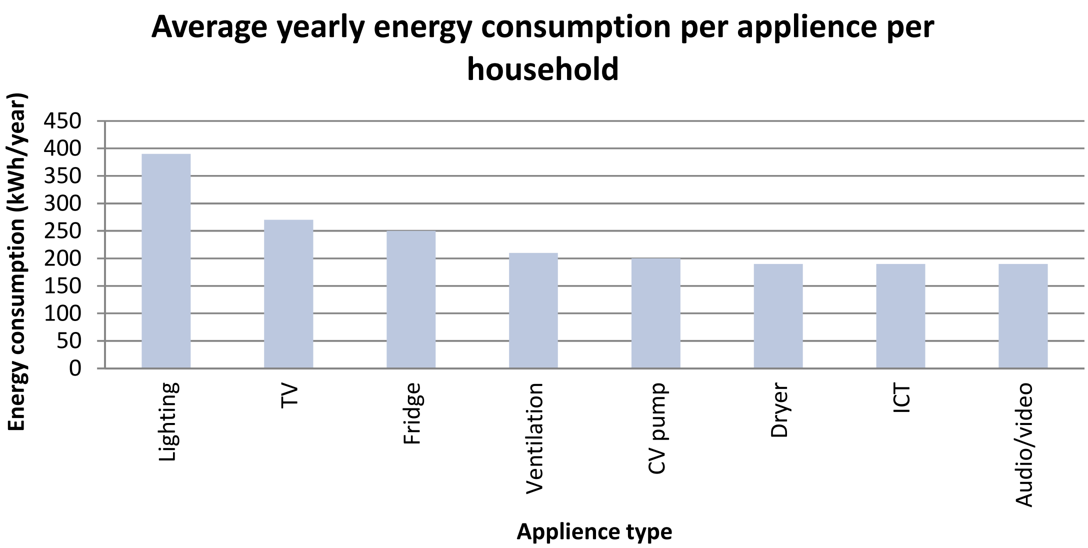

Figure 13 Average yearly energy consumption per appliance per household

Energy efficiency

One way to reduce energy demand is to increase the energy efficiency of electrical loads. Replacing light bulbs by LED or fluorescent lamps could reduce 80% of its electricity consumption (Milieucentraal, 2016b).
Also old appliances could be substituted by new, more energy efficient ones. The difference in electricity demand for a television and a fridge, the second and third highest load, are shown in the Figure 13 (Milieucentraal, 2016f) (Milieucentraal, 2016d).
When households are shifting away from gas, this has also influence the way of cooking. Induction could be an alternative. An average Dutch household requires 37 m3 gas per for cooking, for induction this would be about 175 kWh (Milieucentraal, 2016e).

Power and energy

A fridge and a freezer have a high annual electricity demand; nevertheless, these are turned on all the time resulting in a constant load. Appliances which in most cases are used for production of heat in a short time, such as dishwasher, dryer, washing machine, boilers, require high power peaks (Hayn, Bertsch, & Fichtner, 2014). (Borg & Kelly, 2011) give an overview of various appliances and the required power during operation. It shows the difference in power between the constant loads such as the fridge and appliances that are used for a much shorter time such as an oven.

Appliance	Required power [w]
Fridge & freezer	80-250
TV (LCD)	31-421
Microwave (cooking)	700-1300
Electric oven	1000-3000
Electric water heater	1000-3000

Laptop	40-100
Desktop	50-175

Table 8 Required power per appliance

As described before, transition from cooking on gas to induction influences on the power output. The power of one induction cooking plate could be 1400 watt (Menkveld, 2014). This could increase the peak demand enormously if for example three plates are used at the same time at full power.

Appliances could become more energy efficient due to shorter operation time resulting in a lower total energy demand, not per se a lower power peak. For example by turning off standby mode or improvement of insulation of a hot boiler. A second way of increasing energy efficiency of appliances is to reduce the power demand which could also result in an energy reduction. (Borg & Kelly, 2011) provide an overview of the estimated energy efficiency reduction (in power demand) in a period between 2008 to 2020. These factors are based on UK data.

Appliance	Reduction factor power demand
Refrigerator	0.57
Fridge freezer	0.65
TV	0.78
Domestic lighting	0.50
Computer	0.37
Dishwasher	0.85-0.90
Washing machine	0.90-0.96

Table 9 Reduction per appliance

Table 9 shows that it is expected that domestic lighting could be reduced by half, while washing machine and dishwasher could only be reduced with 10% in power demand. In this research different Italian households were modelled and their potential for replacing old appliances with energy efficient ones. This resulted in an average reduction of electricity consumption by households of 23%, depending on the amount of appliances. While the yearly electricity demand could be reduced with energy efficient appliances, (Borg & Kelly, 2011) suggest to reduce daily peak demands by demand side management or real time tariffs, since this peak demand is more dependent of the sum of all loads and less than a high load itself.

Demand side management

Not all appliances that are used in residential housing, could be shifted in time to reduce peak demand. Most of the loads, such as television, oven, lights, are turned on because the inhabitant wants to use it at that moment. In this research (Klaassen, Kobus, Frunt, & Slootweg, 2016) a survey was conducted about the appliances that the inhabitants participating in a test project, would shift for a lower electricity price. Washing machine, dishwasher and tumble dryer were mostly mentioned, accounting for 16% of the total electricity consumption (Gerdes et al., 2016). With an average annual electricity consumption of 2966 kWh, this would mean that 475 kWh could be shifted.

In this research (Klaassen et al., 2016) inhabitants were stimulated to shift the use of their washing machine to day time, when pv was generation energy or to the night, when the energy price was low. This resulted in a decreased load of 31% in the evening, and an increased load during the day.
Also by (B Asare-Bediako et al., 2012) were washing machine, tumble dryer and dish washer considered as shiftable loads. The following table shows the penetration level and energy demand per time that it is used. Nearly, all households have a washing machine, while a tumble dryer and dish washer is less common.

Appliance	Penetration level (%)	Energy demand per operation (kWh)
Washing machine	95	0.96
Tumble dryer	60	2.40
Dish washer	50	1.24

Table 10 Penetration level and energy demand per time per appliance used

Technologies

There are various developments expected in the load profile in the Netherlands (Veldman, Gaillard, Gibescu, Slootweg, & Kling, 2010). First, an increase due to a growing overall electricity demand. Second, implementation of new heating technologies such as micro CHP boilers and heat pump also increase electricity consumptions. Third, adoption of electric vehicles is expected, which also increases electricity demand. On the other side, an increase in electricity generation is expected from a growing number of solar panels.
(Hayn et al., 2014) suggests that these new technologies have a larger impact than modernizing the appliances that are currently used, as discussed before. The first reason given for this is that these new appliances (heat pump, EV, etc.) have a higher peak demand. On top of that, most of the currently installed appliances are used by people to fulfil their needs at that specific moment (watching tv, cooking, lighting the room, etc.) and are less suitable to shift in time. In contrary, the upcoming technologies are more suitable to shift since these have already some form of storage, for example battery or boiler.

The electrification for example of heating and vehicles, decreases the overall energy consumption, however it will increase the electricity consumption (Klaassen et al., 2016).

Replacing traditional combustion engines by electrical vehicles could decrease CO2 emissions and increase the independence from fossil fuels in the transport sector (Halvgaard et al., 2012).

This has significant influence on the electricity profile; not only an increasing electricity demand but also the storage capacity could be enlarged. (Hayn et al., 2014) report that an electric car that drives around 15000 km per year, requires an annual electricity demand of 3000 kWh (with an energy efficiency of 0.2 kWh/km). Many factors determine the charging profile of electric vehicles such as place of charging (work, home, public), charging strategy, battery size (Hayn et al., 2014).

Heat pumps have the ability to reduce the primary energy demand in the residential factor, nevertheless it increases the electricity demand significantly (Hayn et al., 2014). The internship report (Hofgärtner, 2016) shows that a ground source heat pump has significant impact on the electricity demand; it could double the electricity demand of an household. This could be reduced by using pv systems or micro-CHP instead (Hayn et al., 2014). Solar panels could be placed on roofs of building to locally produce electricity. This technology is scalable to the size, orientation and tilt of the roof.

A second way to produce electricity is by sol-called urban wind turbines. Urban wind energy is not widely implemented yet. The price per kWh decreases with the size of the turbine, which makes it more profitable to build a wind turbine outside the city (Wilson, 2009).

Seasonal storage

Most of the heat and electricity is produced by solar boilers or solar panels during summer, while the energy is needed in winter to heat the buildings. Seasonal storage could balance the demand and production. Storing hot water is not desirable due to the large amount of space that would be required and the high energy losses. Thermal chemical storage could be a solution. For example, the heat that is produced in summer by a solar boiler, could be stored in TCM with NA2S (Ard-Jan de Jong et al., 2016). A huge advantage is that there are no thermal losses during the storage. On top of that, TCM has a significant higher energy density, of 2.9 GJ/m3, compared to water at 0.2 GJ/m3 (with 50 ^{o}C difference).

5.3 Focus of model

The scope of this research is on the energy balance of a neighbourhood. Measures can be applied on two levels: the building level and the city level. The type of improvements are described for both levels according to the Trias Energetica. Thereafter, is explained how these improvements are implemented in the model. Finally, is illustrated how the model is applied.

5.3.1 Measures on building level

As shown before, energy for electricity, heating and transport are all a significant part of the energy consumption of a household (Gerdes et al., 2016).
The energy demand for electricity is the smallest part. Improvements of energy efficiency of currently used appliances are not primarily the focus since the energy reduction that can be achieved is small in comparison with the new loads. Since lighting is the highest consumer of electricity in a household, the replacements by LED lights in houses are included in this research. Solar panels are chosen to produce electricity locally. Urban wind energy is not considered due to nuisance issues; besides it is not widely implemented and the potential of producing energy is larger outside the urban area.
Gas demand is a large part of the total energy consumption. Therefore, a heat balance model is implemented as well. The heating demand can strongly be reduced by insulation, triple or glazing and heat recovery of ventilation air. An additional energy reduction can be achieved by replacing the gas heating by ground source heat pumps. Heat pumps can have a significant influence on the electricity grid. Therefore, the option is explored to combine a ground source heat pump with solar boilers and a seasonal storage based on TCM.
Transport by cars accounts for almost one third of the total energy demand of households. By using electric vehicles an energy reduction can be gained. Nevertheless, charging electric vehicles increases (peak) electricity demand. The impact of where the cars are charged (at home or at work) are frequently researched lately.

(Hayn et al., 2014) show that not only electric appliances and new heating and electricity generation determine the energy profile of residential houses, also softer factors play a significant role: lifestyles and socio-demographic factors. The number of people per household, income, age and employment status are the main socio-demographic factors that are influential. (Hayn et al., 2014). The only factor that is considered in this research is the number of people per household, other factors are out of scope, though worthwhile to examine in further research.
Energy that is needed to produce food and consumption products is out of scope as most of these products are produced outside of the neighbourhood.

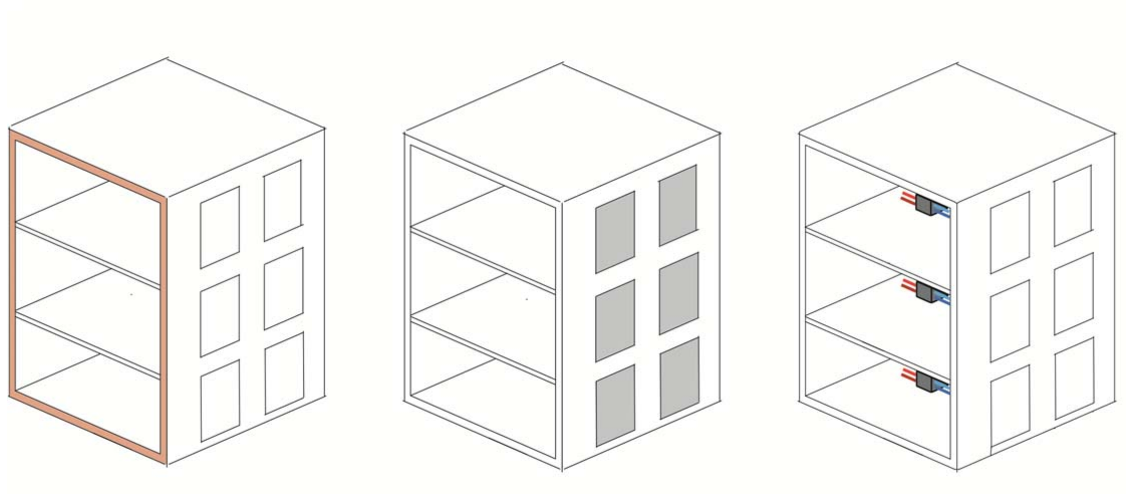

Figure 14 Measures to reduce heating demand

The Figure 14 shows some measures that can be applied to reduce the heating demand. The improvements are good insulation, triple layered glass and balanced ventilation with heat recovery.

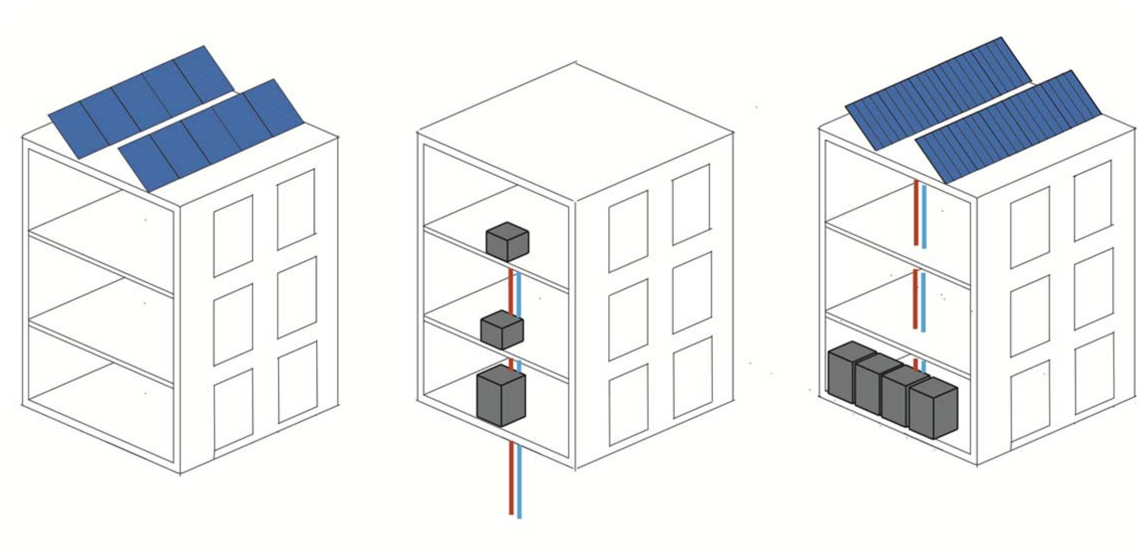

Figure 15 Measures to produce energy

The figure shows the measures that can be applied to produce energy. Firstly, electricity can be produced by installing solar panels. Secondly, a ground source heat pump can produce heat in the building. In such a configuration, a final measure could be to produce hot water with solar boilers and store the heat in a heat battery of TCM's.

5.3.2 Measures on city level

There are different type of measures that could be taken by the municipality to reduce energy in the city. The first type of measure is the role as facilitator: providing information, financial support or bringing parties together to collaborate. The second way is to change

the energy profile of the portfolio owned by the municipality directly. Besides buildings owned by the municipality, other fields where energy could be reduced in the city are: public transport, street lighting and pumping stations. These energy streams belong to the energy consumption of the whole city. These particular energy demands are in general not included in a households energy bill; however, inhabitants are indirectly charged for it via taxes.
This research is on neighbourhood level, which is not in the range to influence the public transport system. The potential of reducing energy with street lighting and pumping stations will be researched.

5.3.3 Power and energy

Most of the researched papers about demand side management, charging strategy of EV's, heat pump operation or storage focus on power neutrality.
Improvements from the perspective of buildings such as insulation, energy efficiency improvements of appliances mostly focus more on energy neutrality.
Instead of optimizing the operation of for example a heat pump, other measures such as insulation or orientation of the building, could have more influence on reduction of peak power. This relation between the built environment and the power output is only limited discussed in the literature found.
Therefore, it is chosen to focus on how the built environment could be changed or adjusted to become energy neutral and improving the power neutrality.
The scope is not on improvement of charging or operational strategies. This means that demand side management is not considered. Additionally, only one charging strategy for EV's and one operational strategy for heat pumps is applied to limit the number of variables.

5.3.4 Type of case study chosen

Gas and electricity demand is highly dependent on the user and the building. It is chosen to test this model in a case study. In this way real data can be used as input for the model and to the relationship between the built environment and its energy use. The main focus will be on residential district. A case study of a neighbourhood is chosen which includes various types of buildings to compare the differences in energy demand and supply.

5.4 Summary

The goal of this model is to combine planning, design and operation in order to come to an integral approach. These happen in different phases, levels and have different goals. By integrating operation already in the planning and design phase of the neighbourhood, peak loads could be prevented. This can reduce storage capacity and reinforcements of the grid. The main fluctuations in demand and supply, such as day and night, weekday and weekend, can be covered by using a time step of an hour and a time horizon of one year.

The aim of this research is to find the relationship between the built environment and the energy performance, having the goal to discover how the neighbourhood could become energy neutral. Different scenarios will be compared and showing the influence of one or a combinations of improvements.

The model will be applied to an existing neighbourhood taking into account measures that can improve the energy demand of heating, electricity and transport. The impact of improvements are considered on an hourly and yearly basis. The measures, on building and neighbourhood level, are: insulation, ventilation with heat recovery, heat pump, solar panels, energy efficiency lighting, electric vehicles and seasonal storage combined with a solar boiler.

6 **Description model**

6.1 Case study

A case study neighbourhood in the city of Rotterdam is chosen, located in the district Prins-Alexander.

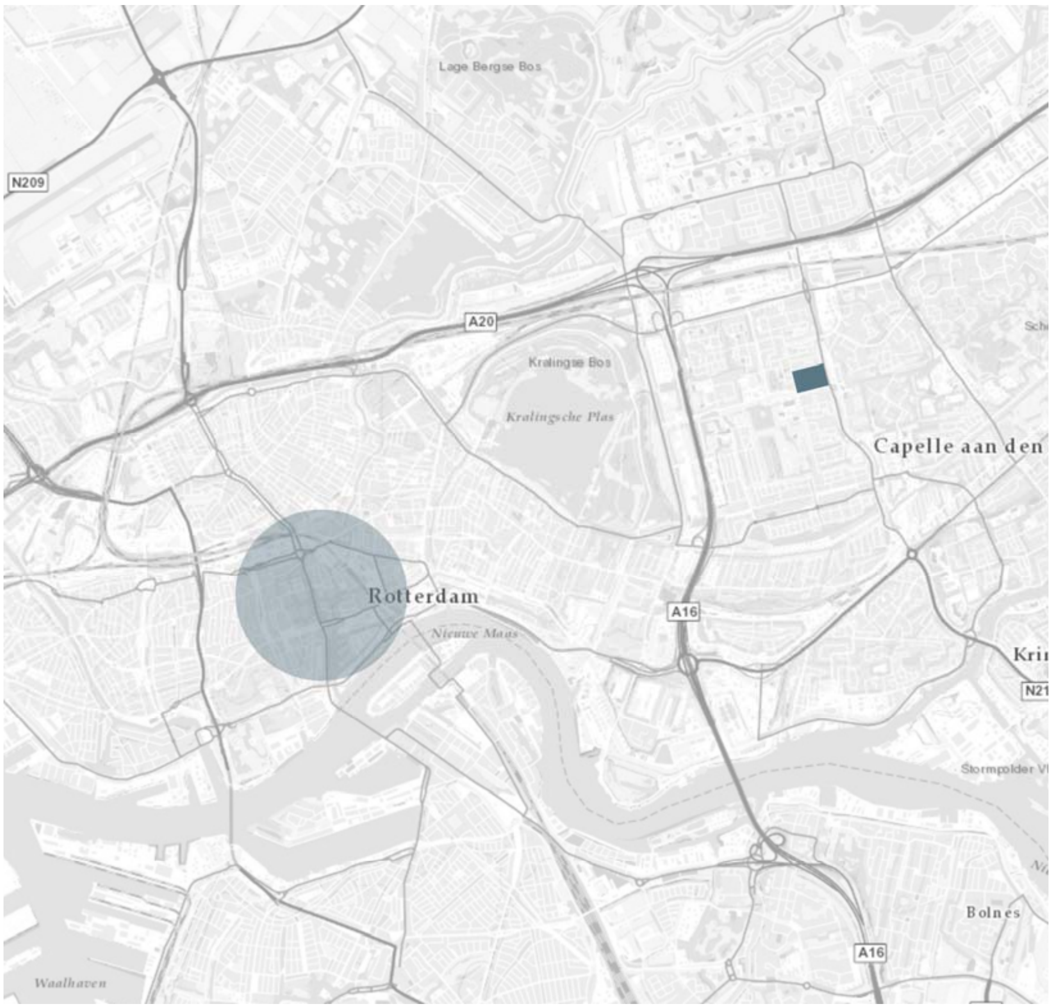

Figure 16 City centre of Rotterdam (left) and case study area in Prins-Alexander (right)

It has four different type of buildings that allow a comparison between their energy profile. The case study contains row houses and three type of flats, shown in Figure 17 (Hofgärtner, 2016). In total there are 324 households in this area.
c

Figure 17 Buildings case study

As described in (Hofgärtner, 2016) this case study is chosen because the gas and the sewage infrastructure needs to be renewed next decade. This would be a good moment to replace the heating infrastructure as well with a renewable energy system. On top of that, the buildings are built around 1965. These buildings were renovated over time. However, it is expected that a deep renovation will be needed soon. Renewing the underlying infrastructure and deeply renovating the buildings, could be a suitable moment to combine a renovation with a new energy system. More background information can be found in internship report (Hofgärtner, 2016).

Figure 18 3D view of case study

Type	Flat type 1	Flat type 2		Flat type 3			Row houses			
Building	A1	B1	B2	C1	C2	C3	D1	D2	D3	D4

Table 11 Overview of buildings in case study

Figure 19 Overview case study

6.1.1 Criteria comparison different buildings

There are different criteria that can be used when assessing the energy profile of the neighbourhood. The demand for heating of the various building typologies can be compared per households, per m2 apartment or per inhabitant. When presenting the heating demand per household, a larger apartment could have a larger energy demand compared with a small apartment. When assessing these two type of buildings based on the area of the house, the larger apartment might have a lower energy per m2 than the apartment. The same applies for comparing two similar apartments, based on the number of inhabitants. If the first apartment has one inhabitant and the second has two inhabitants, the energy demand per person is lower for the second apartment.
A similar situation is also the case for electricity and transport. For example, the energy demand for driving a car, could be presented per household, per person or per car.
In order to communicate between the different type of energies, it is chosen to compare the energy profile based on households. However, this is not always a fair comparison. The row houses could have a larger energy demand because the building is larger and not their energy performance. Therefore, in some cases an alternative option will be presented. For example, heating demand per m2 and energy demand for driving per car.

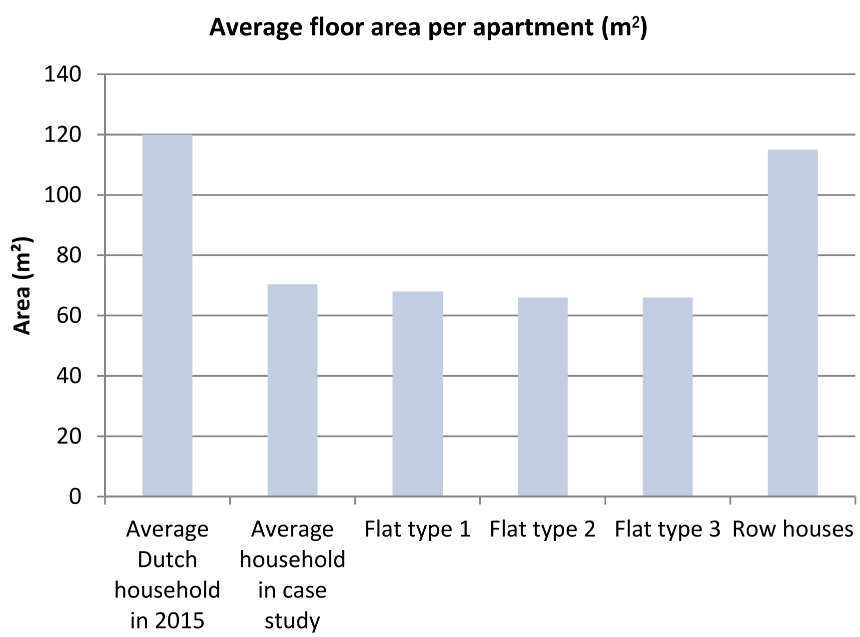

Figure 20 Average floor area per apartment

The average floor area per apartment is compared with the Dutch average (CBS, 2013). Also the number of persons per house (Gerdes et al., 2016) (Hofgärtner, 2016). The Dutch average floor area is similar to the floor area of a row house, while the number of persons are higher. The primary energy demand of the row houses is similar to the Dutch average. The flats have a lower energy consumption; these have a lower floor area and number of people per apartment. The primary energy consumption is the result of the calculations of the energy demand that will be explained in this chapter. It is not known how the energy demand for transport is distributed among the different type of households. Therefore, the average per household of the case study neighbourhood is presented in Figure 22.

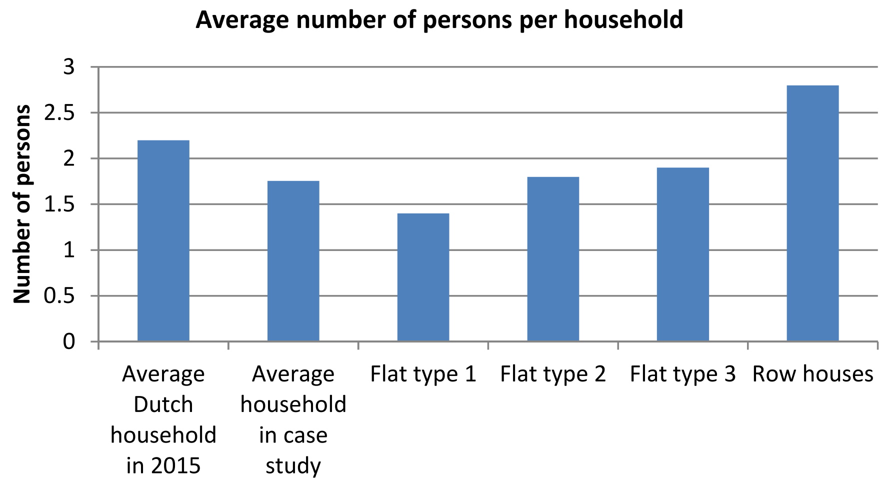

Figure 21 Average number of persons per household

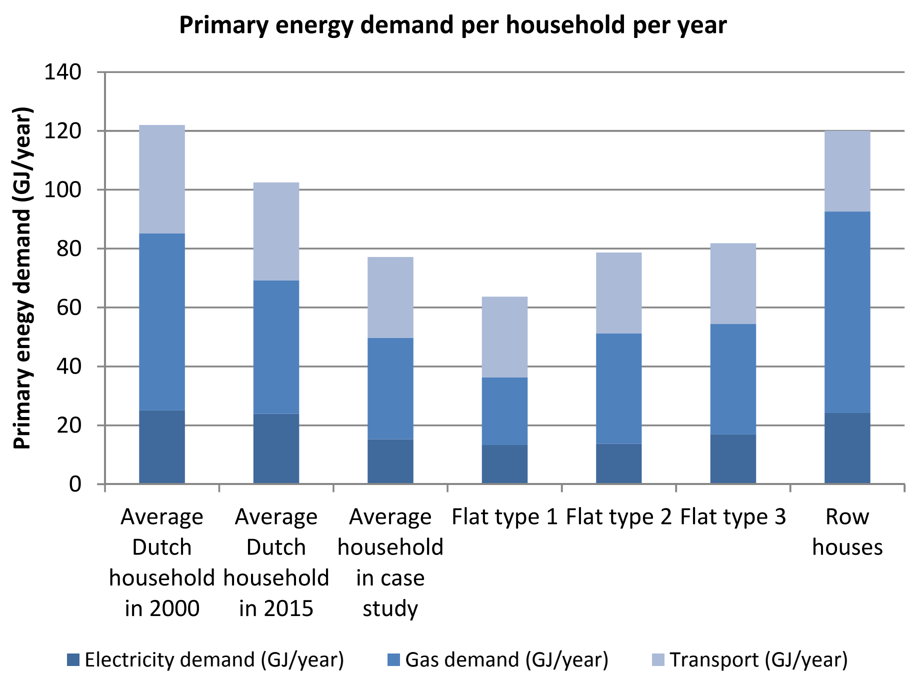

Figure 22 Primary energy demand per household per year

6.2 General

In this chapter general information about the model is explained; the influence of the chosen data and how the time step and time horizon are worked out. Finally, it is shown how the energy balances are calculated.

Data

This model requires input from many data sources. The data that are used has a significant influence on the outcomes of the model. In some cases, sub-optimal data are used since there were no other sources available. Two main remarks have to be made about the data that are used.

Firstly, data sources are used from different years. For example, the yearly electricity demand of the households in the case study are from 2013, while a reference year is used as input for weather data such as temperature and radiation of the sun (NEN 5060, 2008).

Secondly, the combination of general and specific data is sub-optimal. On one hand, average Dutch information is used. On the other hand, specific data from this neighbourhood was used. Also here there is a great variety. For example, the energy consumption per household is in this neighbourhood about 30% less than the average Dutch household. Also this could have significant influence on the outcomes of the model. Measures applied in this case study could have a different outcome in another type of neighbourhood.

Table 12 shows data which apply to Dutch averages and specific for the case study. This illustrates that there is a substantial difference between the general and specific input.

Households	Netherlands, 2015 (Gerdes et al., 2016)	Case study
Number of households	7.665.000	324
Number of persons per household	2.2	1.8
Gas consumption per household (m^3)	1432	1087
Electricity consumption per household (kWh)	2966	1896
Fuel (petrol, diesel, LNG) for cars per household (Litres)	964	796

Table 12 General and specific energy demand data

Time step

As described in chapter 5, the model will have a time step of one hour and a time horizon of one year. Initially, one summer and one winter week with an hourly time step was chosen. This shows how the outside temperature and the position of the sun influence the energy profile. However, this would only give information about the extremes (winter and summer). The insights that could be gained are limited. For example, it would be harder to estimate the total energy consumption and production during one complete year.

In conclusion, it was chosen to use weather data of one year containing 8760 hours. This makes it possible to compare load profiles of different weeks and calculate the yearly energy consumption and production. In this model, summer time is not considered. The time steps of one hour are the average values during that hour. A time step that is registered as 02:00, means that it is the average energy demand or production during the time period of 01:01 till 02:00.

Weather data

Weather data is needed to include the fluctuations of the outside temperature and the radiation of the incoming sun. These influence the heating demand in buildings, but also the electricity production of solar panels. At first, data from KNMI were used from the year 2010 which was one the coldest winters last two decades.
Using data from one specific year has the drawback that is hard to compare the results with other studies. Therefore, it is finally chosen to use the reference year (NEN 5060, 2008). The dataset includes hourly data of ambient temperature, diffuse and direct radiation. More information about the datasets can be found in annex B.

Total energy

Different measures are applied to the case study to improve the energy performance, shown in Table 13.

Type of energy	Scale	Scenario 0	Measures
Electricity	**Neighbourhood**	Load profile street lights	LED lighting + dimming
	Building	Load profile	LED lighting
			Solar panels
Heating	**Building**	Gas kettle	Heat pump
			Solar boiler + heat battery (only row house)
		Energy performance building	Improved insulation + glass
			Heat recovery ventilation
			Reduction of infiltration rate
Transport	**Neighbourhood**	Cars on fossil fuel	Electric vehicles
			Charging strategy at home / work

Table 13 Measures applied to case study

Scenarios with different combinations of technologies and adjustments are modelled as improved situation. An overview of the current and improved situation is presented in Table 14.

A combination of these difference situation can be made in the form of scenarios:

Scenarios	Situation technologies
Scenario 0	LP (C)
Scenario 1	LP (C) + PV
Scenario 2	LP (C) + PV + EV (H)
Scenario 3	LP (I) + PV + EV (W)
Scenario 4	LP (C) + PV + EV (H) + HP (C)
Scenario 5	LP (I) + PV + EV (W) + HP (I)
Scenario 6	LP (C) + PV + HP (C)
Scenario 7	LP (I) + PV + HP (I)

Table 14 Scenarios

The scenarios are composed of the following situations:
(C) = current situation
(I) = improved situation
HP (C) = heat pump provides heating, cooling and hot tap water in the buildings with the current energy performance
HP (I) = heat pump provides heating, cooling and hot tap water in the buildings with the improved energy performance
LP (C) = load profile; electricity demand neighbourhood in current situation
LP (I) = load profile; electricity demand neighbourhood with LED lights
PV = electricity production by solar panels
EV (H) = home charging EV's
EV (H&W) = home and work charging EV's (only cars used to drive to work)
EV (W) = work charging EV's (only cars used to drive to work)

The measures that could be taken to improve the current situation are modelled on an hourly basis. In this way the influence on the electricity grid can be investigated. Some measures result in a higher electricity demand than in the current situation.
An example is the electrification of cars; charging an EV will increase the electricity demand while this could also positively influence the total annual energy balance of the neighbourhood. Therefore, all measures considered in this research, show the impact on the total energy demand on a yearly bases and on the electricity grid on an hourly basis.

The total energy balance for one year is expressed in primary energy (GJ). This includes the efficiency of a power plant to produce energy and allows comparing the different measures with each other, such as solar panels and insulation.

It has to be noticed that the hourly profiles of the model are not expressed in primary energy. When calculating the impact of a measure compared with the current situation, the energy balance is first calculated back to secondary energy. For example, a household uses 2000 kWh per year. The energy content is 7.2 GJ and the primary energy demand is 16.2 MJ. Solar panels are installed and the effect on the net energy balance is calculated. The energy production of the solar panels of 600 kWh is deducted from the secondary energy consumption of 2000 kWh. This results in a net energy demand of 1400 kWh or 5 GJ (energy content) or 11.3 GJ (primary energy).

The hourly energy balances are presented in the model for each building. This is expressed in kWh, except for a part of the heat balance which is expressed in MJ. The annual energy balance is shown for the whole building and per household in kWh and MJ.

Total annual energy balance:

$$E_{tot}(t) = E_{trans}(t) + E_{elec}(t) + E_{heat\&cool}(t) \quad (1)$$

t = years
E_{tot} = energy balance [kWh or MJ]

Hourly electricity balance current situation:

$$E_{elec,tot}(t) = E_{elec,LP}(t) \quad (2)$$

Hourly electricity balance improved situation (all measures):

$$E_{elec,tot}(t) = E_{elec,trans,EV}(t) + E_{elec,LP,impr}(t) + E_{elec,HP}(t) - E_{elec,PV}(t) \quad (3)$$

t = hourly time step
E_{elec}= electricity demand [kWh or MJ]
$trans$ = transport
LP= load profile
$impr$ = improved
HP = heat pump,
PV = solar panels

6.3 Electricity

This chapter about electricity describes firstly how the electricity profile is modelled of the neighbourhood in Prins-Alexander for the current situation. Secondly, it is illustrated how an electricity reduction can be achieved by improving lighting. Electricity reduction in the pumping system by reducing rain water, was also considered. However, this part was very small and not taken into account. More information can be found in annex C. In the last of this chapter the local electricity production by solar panels is reported.

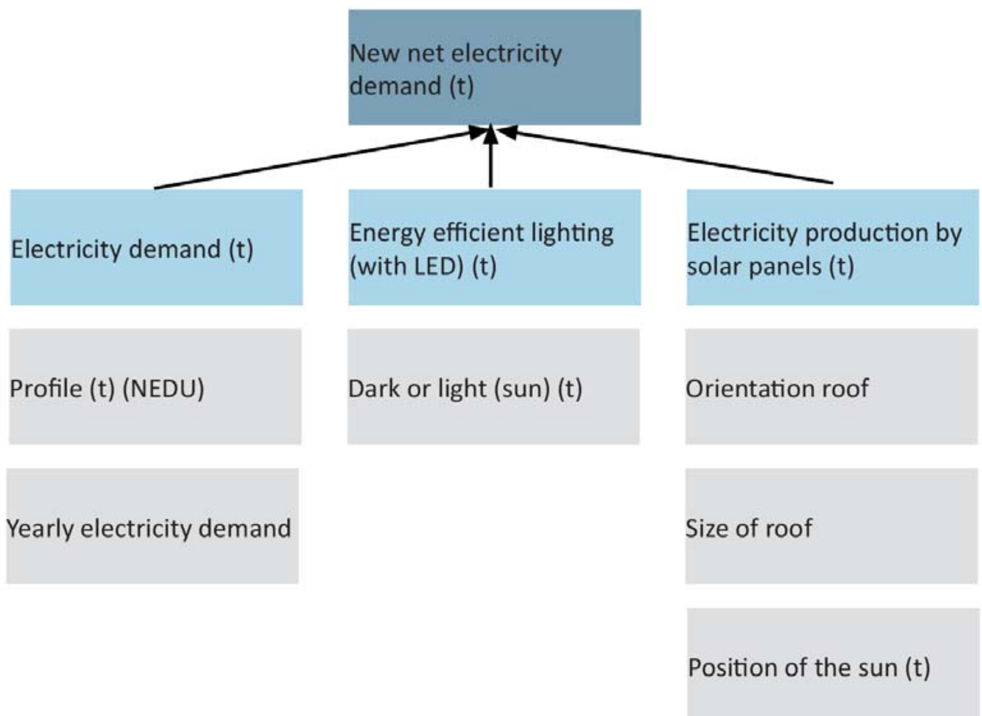

Figure 23 Electricity model

6.3.1 Current electricity profile

Load profiles (NEDU, 2016) This is an average profile of a Dutch household. It is based on 184 households, measured between 2009-2011 (NEDU, 2016). These profiles are used for example by private companies, to estimate the energy demand and to allocate the energy production. In case the estimated energy demand deviates from the actual energy demand, the installed capacity for electricity production is not used as expected. The difference in price of electricity can be paid off (VREG, 2016). It has to be noted that this is an average load profile. The profile can be different for inhabitants from different financial, social, demographic status. This aspect is not within the scope of this research.
Load profiles are available for 2014-2017; for this research the load profile of 2016 is chosen. In (NEDU, 2016) it shows that 2016 and 2015 are nearly the same.

There three types of pricing profiles: type E1A has a single tariff, type E1B has a night tariff (23:00-07:00) and type E1C has an evening tariff (21:00-07:00). A difference in tariff during day time and overnight could change the behaviour of the user. Some small variations can be noticed between the three patterns. However, the main pattern of the three graphs is similar. In this study the single tariff pattern is used for modelling.
Summer time is considered in these profiles, starting from Sunday 27th of March and ending on Sunday 30th of October. This is compensated in the model since no summer time is included. The values of the electricity profile during summer time are moved one hour earlier.
The dataset provides values every 15 minutes; these data points are accumulated to one hour in accordance with the time step of rest of the model. The load profiles are normalised. Each time step is multiplied by the annual electricity demand of the type of building in the case study.

$$E_{elec,LP}(t) = E_{elec\ yearly\ average} * \mathrm{F}_{elec,standard}(t) \quad (4)$$

$E_{elec,LP}$ = electricity demand household $[kWh]$
$E_{elec\ yearly\ average}$ = yearly average electricity consumption per household [kWh]
$\mathrm{F}_{elec,standard}$= standard Dutch electricity load profile EDSN 2016. Normalised values converted from 15 minute to 1 hour time step

The annual electricity demand per type of building is shown in Figure 24. The flats have a lower electricity demand that the Dutch average. The row houses show about the same electricity demand for an average Dutch household. A large difference between the flats and the row houses can be seen. When considering the electricity demand per m2 the buildings show a comparable outcome.

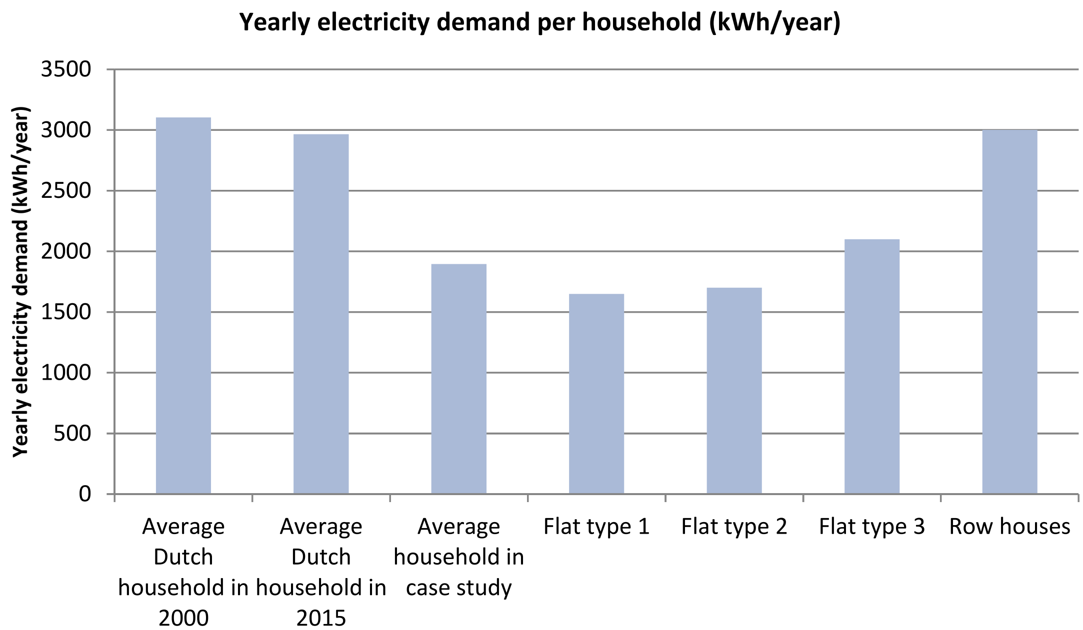

Figure 24 Yearly electricity demand per household (kWh/year)

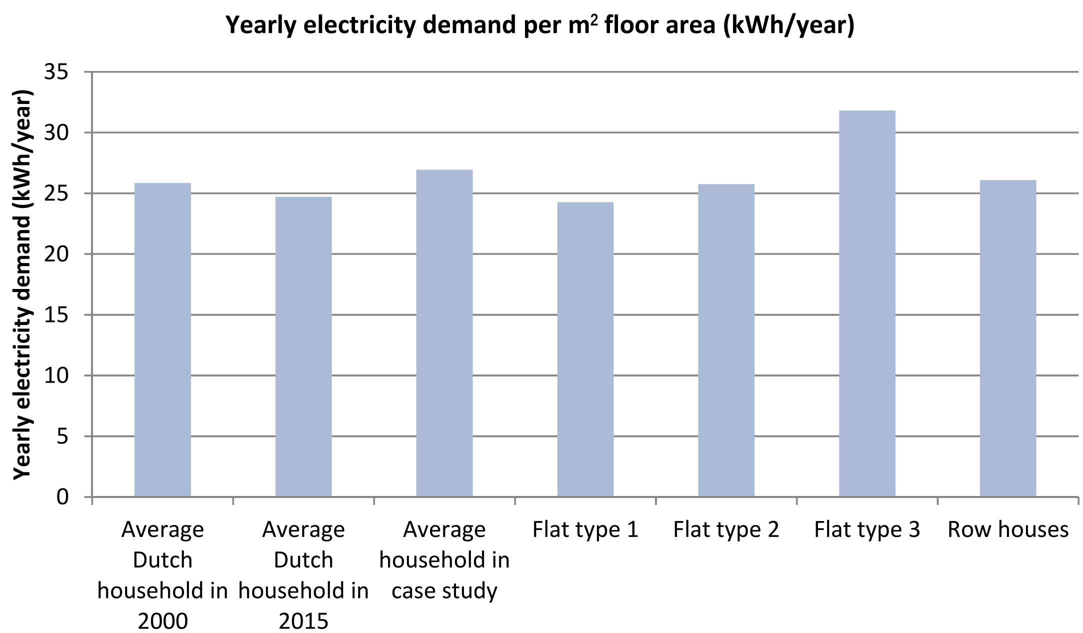

Figure 25 Yearly electricity demand per m² floor area (kWh/year)

6.3.2 Reduction of electricity demand

As shown in chapter 5, there are many possibilities to reduce the current electricity demand. The largest consumer of electricity in an average household is lighting. On second and third place are television and fridge. In this research only lighting is considered as a measure that could be applied to reduce electricity demand. Further research could be carried out to link the different type of appliances present in various types of households to estimate yearly electricity consumption and (peak) power demand.

It is stated in chapter 5 that replacement of light bulbs by LED could reduce 80% of its electricity consumption (Milieucentraal, 2016b). In (Borg & Kelly, 2011) is shown that changed domestic lighting could reduce 50% of its power consumption. Since it is unsure what types of lights are currently present in the buildings, it is assumed that with the replacement of LED 50% of the electricity demand of lighting can be saved. The ratio of electricity consumption by lighting and the total annual electricity consumption is assumed to be the same for each household. The Figure 26 shows the current electricity demand and the new electricity demand after 50% of the energy used by lighting is saved. The resulting situation is an electricity demand which is 7% lower than the current situation.

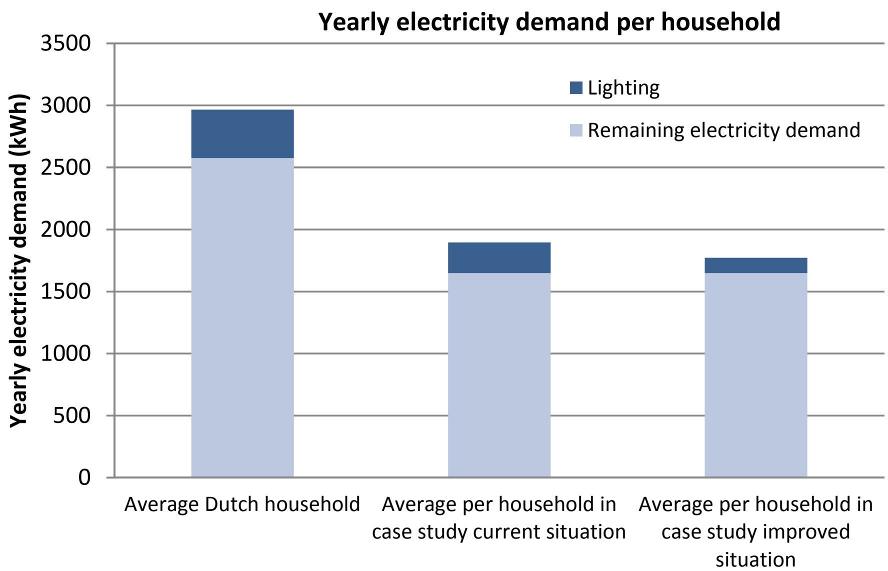

Figure 26 Yearly electricity demand per household

An electricity demand profile of lighting needs to be estimated since there is no exact data regarding. It would be logical to turn on the lights when it is dark outside. The sun simulator can be used for this purpose. It is assumed that 60% of the electricity demand of lighting is consumed during the period 16:00-00:00, only for the hours when it is dark outside. The remaining 40% of the electricity demand of lighting, will be spread out during the rest of the day. No difference was made in the number of lights that are turned on.

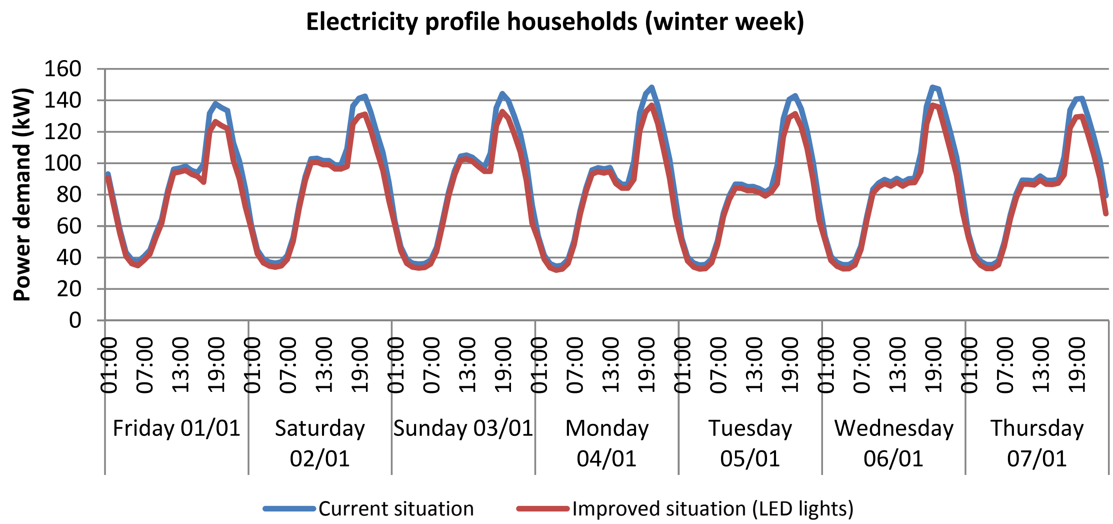

Figure 27 Electricity profile households (winter week)

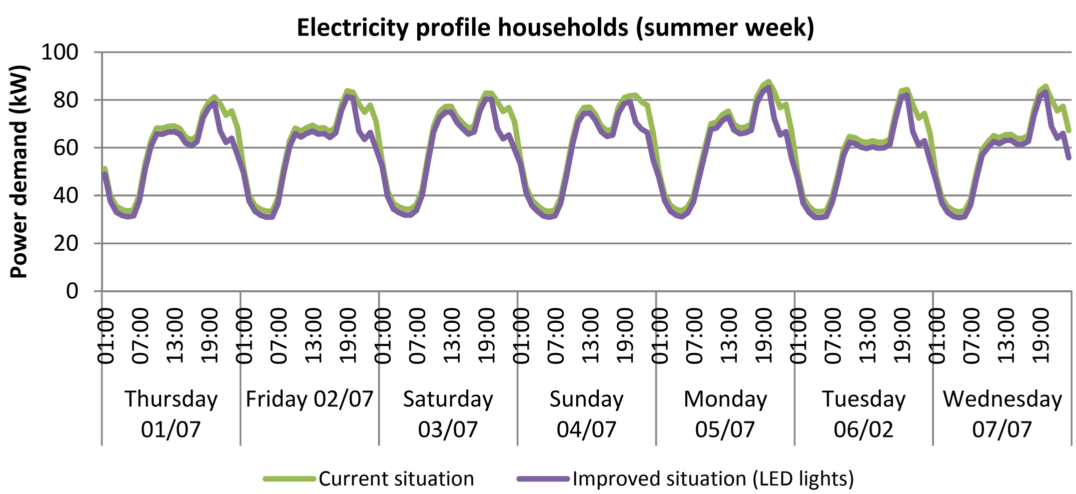

Figure 28 Electricity profile households (summer week)

The Figure 27 and Figure 28 show the electricity profile of the households. Firstly, can be noticed that the electricity demand is higher in winter than in summer. When electricity demand is reduced with LED lights, it shows a smaller peak in winter and in summer time. The peak reduction has a larger impact in summer time than in winter compared to the initial electricity demand. The sudden decrease is the moment that the sun sets. The difference between electricity reduction in winter and summer time is only shown in the number of hours that the lights are turned on, not in the number of lights.

Street lighting

The street lights turn on just about after sun set and they are turned off again right before sun rise during twilight. This results in 4160 hours per year (Wijnands, P., personal communication, December 2016), which is centrally turned on for the whole city.
Using the sun simulator from chapter 6 that has been built for the simulating the energy production of solar panels, the number of hours where street lighting is required is calculated. The definition for "street lighting required" is set for the altitude of the sun is below zero degrees altitude. This leads to an overestimation of the number of lighting hours. The barrier of the altitude is adjusted in such a way that is has the same number of hours as the current real life situation. This is achieve with an altitude of -2.25 degrees; the corresponding lighting hours for this setting are 4162.
The neighbourhood has 62 street lamps, there are two different types shown in annex C. According to (Wijnands, P., personal communication, December 2016) an additional 7% energy consumption has to be added to the power of the current lamps due to the system losses.

	Current situation	Improved situation with LED lamps	Improved situation with LED lamps + dimming at night
Power total neighbourhood (watt)	3606	2864	2864
Yearly energy demand (kWh)	15008	11920	8261
Energy reduction regarding current situation (%)		21%	45%

Table 15 Reduction current lighting with LED

The table shows that a reduction of 21% can be achieved by replacing the current lighting with LED. A second option to reduce street lighting is to implement a dimmer. It is recommended to decrease the light intensity to 50% between 23:00 and 06:00 (Wijnands, P., personal communication, December 2016). With this measure 45% of the electricity could be saved compared to the current situation. The electricity that could be saved is 3.5 times the average yearly electricity consumption of one household in this neighbourhood. An advantage of LED lights is that the system losses are nearly zero (Wijnands, P., personal communication, December 2016). This means that the energy demand of LED lights, that are suitable for dimming, decreases almost proportional to the light intensity in contrary to light bulbs or halogen light (Milieucentraal, 2016b).

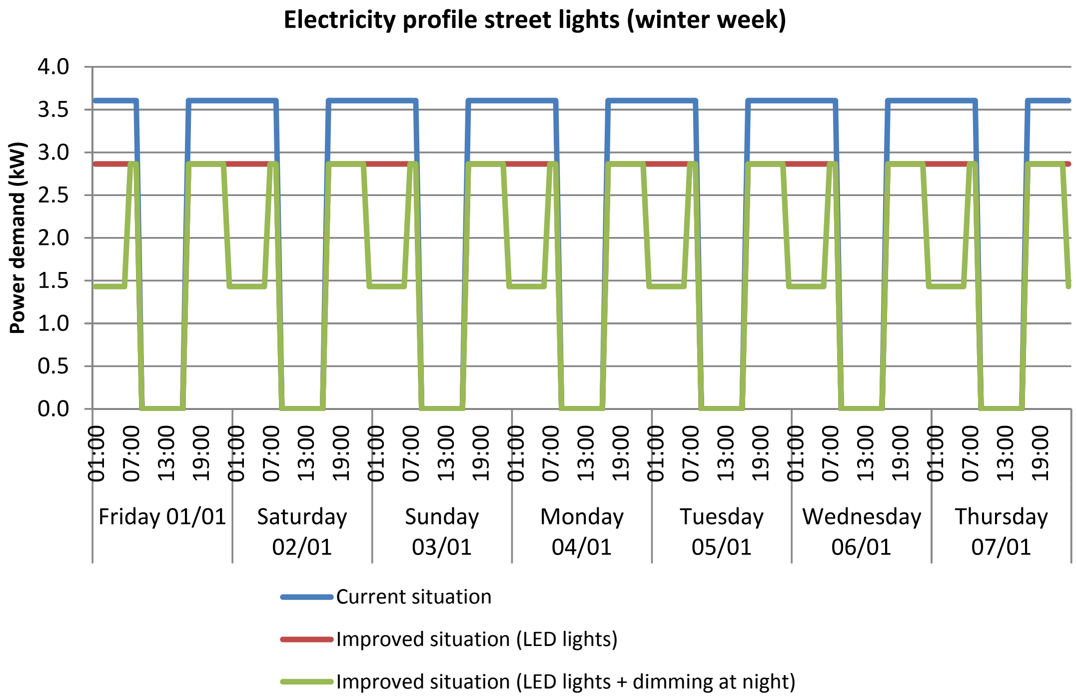

Figure 29 Electricity profile street lights (winter week)

Figure 29 shows the electricity profile of the street lights. Replacement of current lamps with LED has an overall peak decreasing effect, whereas dimming at night has especially a peak decreasing effect during the night.

6.3.3 Electricity production

Solar energy is an important source that could be used to produce energy locally. The production depends on the orientation and tilt of the panels. It is not always possible to place the solar panels in the optimal orientation and tilt due to the form and orientation of the buildings and the tilt of the roofs. The path of the sun will be needed to model the energy production of solar panels with a hourly time step. Therefore, a sun simulator has been built, see annex C.

Energy production solar panels

The energy production by the panel are calculated with the NOCT model, which makes the output dependent on the temperature of the module (Chandra Mouli, Bauer, & Zeman, 2016). High temperatures decrease the performance of the solar panel.

$$T_{cell} = T_{amb} + (I_{glob,p}/I_{noct}) * (T_{noct} - 20) \quad (5)$$

$$P_m = (P_r \cdot I_{glob,p} / I_{stc})(1 - \lambda_{pv} (T_{cell} - 25)) \quad (6)$$

I_{noct} = irradiance under test conditions NOCT = $800\ [W/m^2]$
I_{stc} = irradiance under standard test conditions = $1000\ [W/m^2]$
$I_{glob,p}$ = global irradiance on panel
P_r = rate power [W] (provided by solar panel manufacturer)
λ_{pv} = module temperature coefficient $[\%/°C]$

The overall losses of the system until the AC output are assumed as 10%. This consists of (Burger & Rüther, 2006) & (Jäger, Isabella, H.M. Smets, R.A.C.M.M, & Zeman, 2014)

- Inverter losses = 6 %
- Mismatch between modules = 1.5%,
- MMPT mismatching = 1 %
- Ohmic cable losses 0.5 %
- Soiling = 1%

Total power production is modelled as:

$$P_{out,tot} = n \cdot P_{out,p} \cdot ή_{sys} \quad (7)$$

$ή_{sys}$ = overall efficiency system
N = number of panels
$P_{out,tot}$ = power output from pv system ac [W]

Panel

For this study the Sun power module E20 – 327 is chosen (Sunpower, 2016).

Specifications of the solar panel are:

Length module	**1.05 m**
Width module	1.05 m
Area module	1.68 m2
Nominal power (Pr)	327 Watt
λpv	0.0038 fraction/c degrees
Ambient Temperature	20 C degrees
Tnoct	45 C degrees

Table 16 Specifications solar panel

The roof area on the buildings in the case study is limited. Therefore, it is chosen to use the space efficiently by installing high performance solar panels. This panel has a nominal power of 204 Wp/m2. A market research has been carried out about the available solar panels. These range from 69 – 204 Wp/m2 with an average of 143 Wp/m2. It is clear that the Sun Power module E20-327 is one of the best performing panels that are available (van Sark & Schoen, 2016).

System design for case study

The neighbourhood that is used as case study contains buildings that differ in size, orientation and shape of the roof. The solar panels will be placed on these roofs in different configurations to compare the results. The goal is to match yearly supply with yearly demand so far as possible for the whole neighbourhood. Solar panels produce more electricity during summer than winter, which makes it harder to cover the total electricity demand in winter. The placement of the solar panels could be different for each roof in order to get the best result for the whole neighbourhood.

The shadow that is casted by other buildings on the roof is limited. Therefore, this is not taken into account in the design of the solar panel system. In an urban area with larger differences in height between the buildings, this is important to take into account as well. Partial shading of a solar panels can cause hot spots which could decrease the performance of the pv system (Jäger et al., 2014).
Table 17 provides an overview of the various buildings in the neighbourhood and difference in orientation and tilt. The roof area is the flat area, which means that the actual roof area for the row houses is larger.

Orientation [0,360], south is 180 degrees.
Tilt [0,90], flat is 0 degrees.
It is assumed that only 45% of the roof can be used to install solar panels. The remaining area is not suitable due to building installations and chimneys, casting a shadow each.

Buildings	Flat type 1	Flat type 2	Flat type 3	Flat type 3	Row houses
	A1	B1 & B2	C2	C1 & C3	D1 – D4
Roof area (m2)	1737	968	683	683	296
Orientation length (°)	165	165	165	255	75 & 255
Tilt (°)	0	0	0	0	30

Table 17 Specifications roof per building type

In this neighbourhood, there are two types of roofs: flat and gables roofs. When placing solar panels on a gable roof, the installation possibilities are limited because the roof has already a tilt and an orientation. Therefore, the panels that are placed on the gable roofs, are installed according to the tilt and orientation of the roof. Most of the buildings in this neighbourhood have a flat roof. The orientation of the buildings is not fully towards the south, but 15 degrees turned towards east. A maximum energy production would be achieved by orienting the panels south wards. However, it might be that more panels could be placed on a roof if they are aligned with the shape of the building. These two results will be compared.

Shading

The distance between two rows of solar panels is taken as three times the length of the panel, which is 4.8 meters. More about these calculations can be found in annex C.

Electricity profile

The annual electricity production per household per type of building is shown in the Figure 30. Flat type 1 has a small roof area compared to the number of apartments, resulting in a low electricity production per household. In contrary, the row houses can produce more than three to four times the electricity production of the flat apartments. In all cases is the electricity demand higher than the production. Although the electricity demand of the row houses is higher, it can provide a larger amount of its demand compared to the other building types. As described before in chapter 6.1.1 there are various ways to assess the energy demand and production of different type of buildings. A figure based on electricity demand per m2 can be found in the annex D.

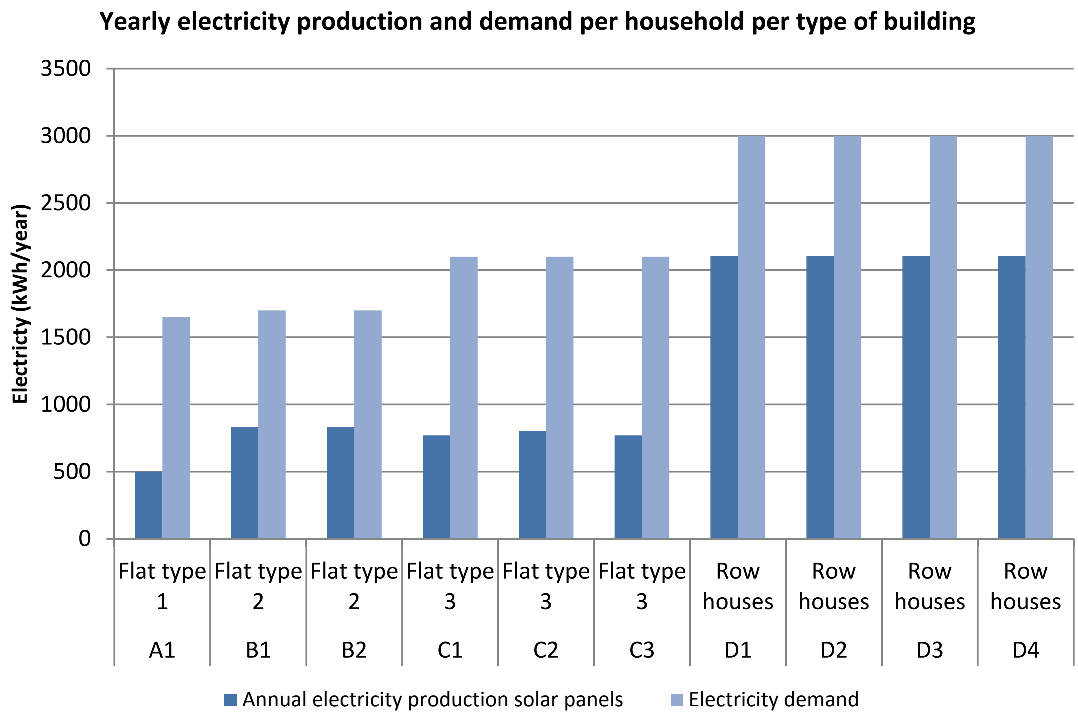

Figure 30 Yearly electricity production and demand per household per type of building

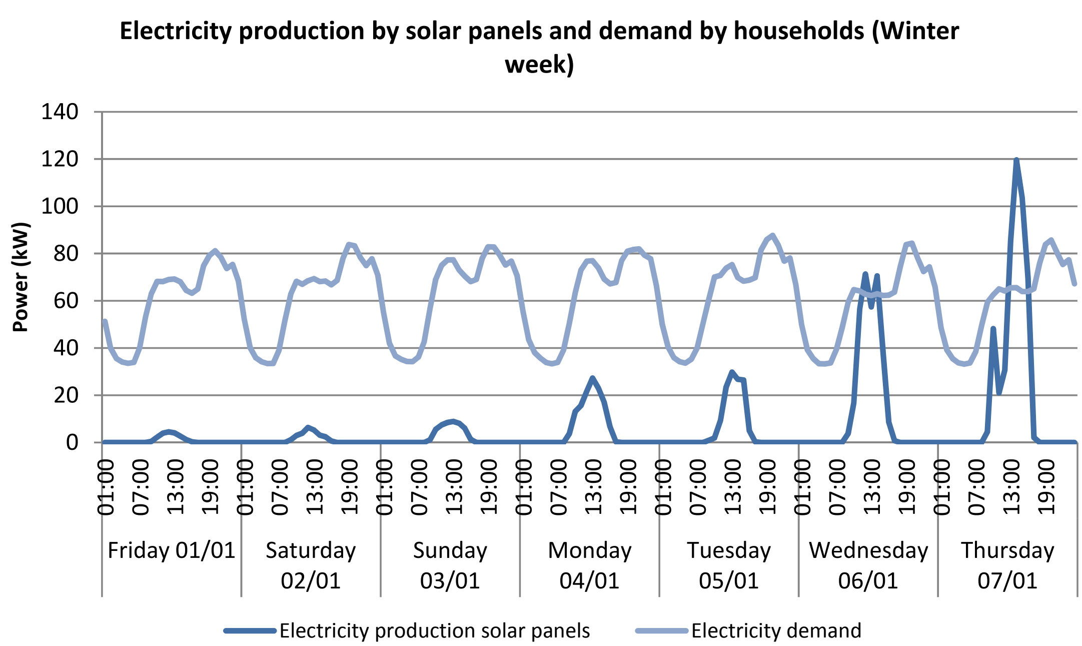

Figure 31 Electricity production by solar panels and demand by households (Winter week)

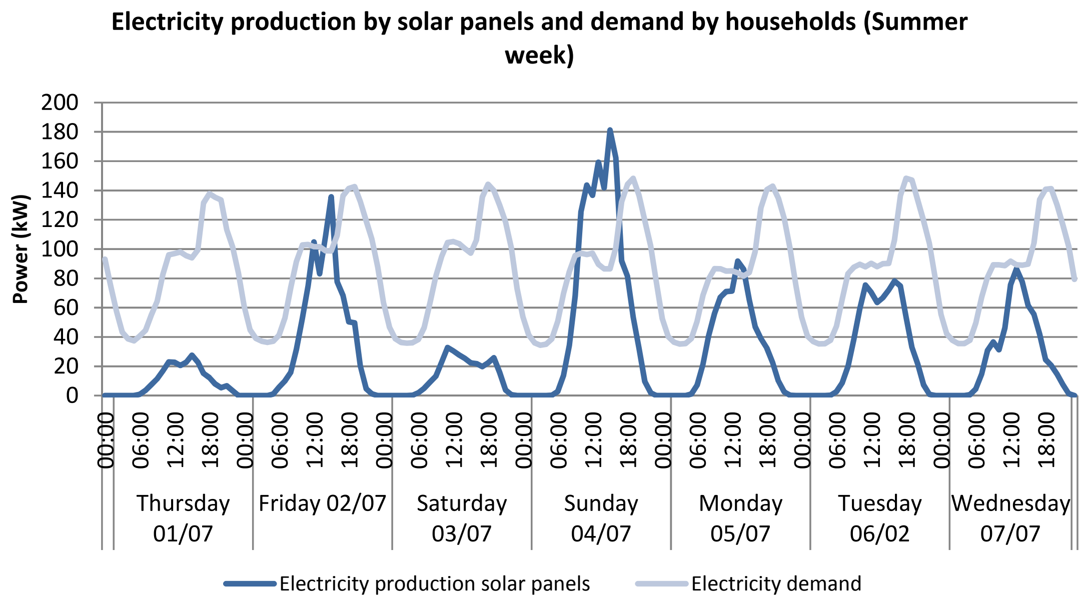

Figure 32 Electricity production by solar panels and demand by households (Summer week)

The electricity demand of the households and the electricity production by solar panels is shown in the Figure 31 and Figure 32, for a winter week and a summer week. Electricity is produced during day time, while the mean peak is in the late afternoon and evening.

Orientation solar panels

Most of the electricity produced by solar panels is during day time, while the electricity demand of the households show a peak in the late afternoon and evening. In order to match production and consumption with each other, the solar panels could be oriented towards the west. In this way, the electricity production is moved slightly later, when the electricity demand is higher.

Instead of orienting the solar panels according to long side of the building, there are now turned 90 degrees towards the west. This is not applied to the row houses, which have a gable roof. The result is shown in the Figure 33 for a summer week and Figure 34 for a winter week.

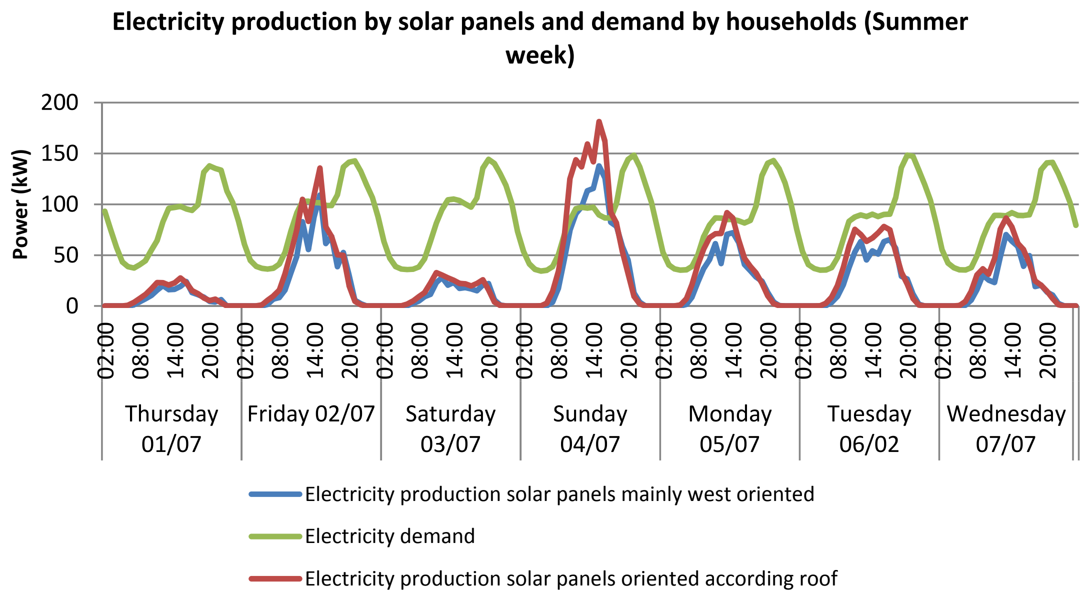

Figure 33 Electricity production by solar panels and demand by households (Summer week)

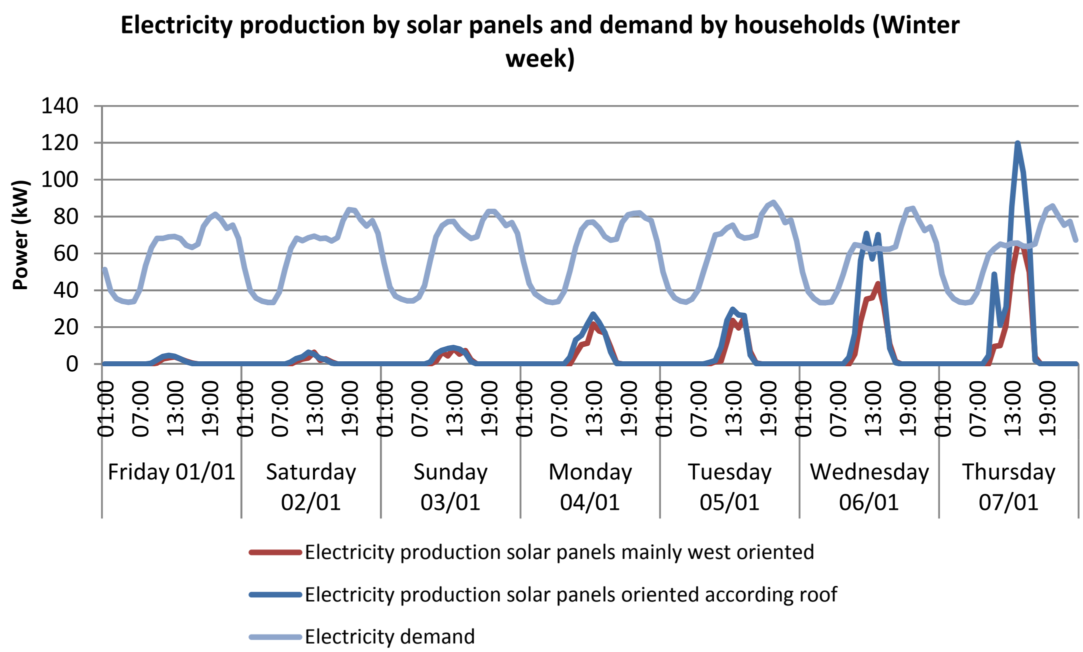

Figure 34 Electricity production by solar panels and demand by households (Winter week)

The effect is very minimal. It is mainly resulting in a decrease of electricity production due to the configuration of the solar panels on the roof. When orienting the panels along the long side of the building more panels can be placed than orienting to the short side. The last situation results in many rows behind each other. Because a distance between the rows is

needed due to the shadow casting, the space is used less efficient, resulting in a reduced amount of installed panels.
In conclusion, in this case study it is not advantageous to change the orientation of the panels. However the effect of orienting the building according to the load profile can be tested by comparing the three flats type 3. These flats have the same size but two different orientations. One building is oriented with its long side towards south (SSE, 165 degrees), the other two buildings to the west (SWW, 255 degrees). Figure 35 shows that the yearly electricity production of the two orientations is similar. As comparison, panels are placed towards the west on the south oriented building. This shows the enormous decrease in yearly electricity production due to the configuration of the solar panels on the roof.

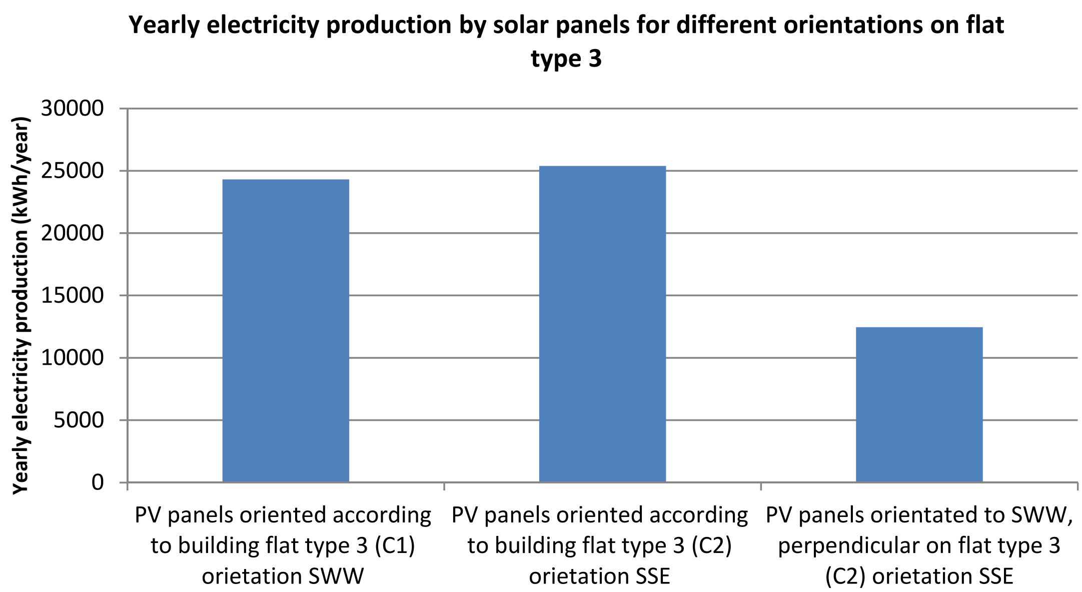

Figure 35 Yearly electricity production by solar panels for different orientations on flat type 3

A winter week and a summer week are shown in Figure 36 and Figure 37. A small shift in time can be noticed between the west and south oriented panels. This has a larger impact in summer than in winter because the days a shorter in winter.

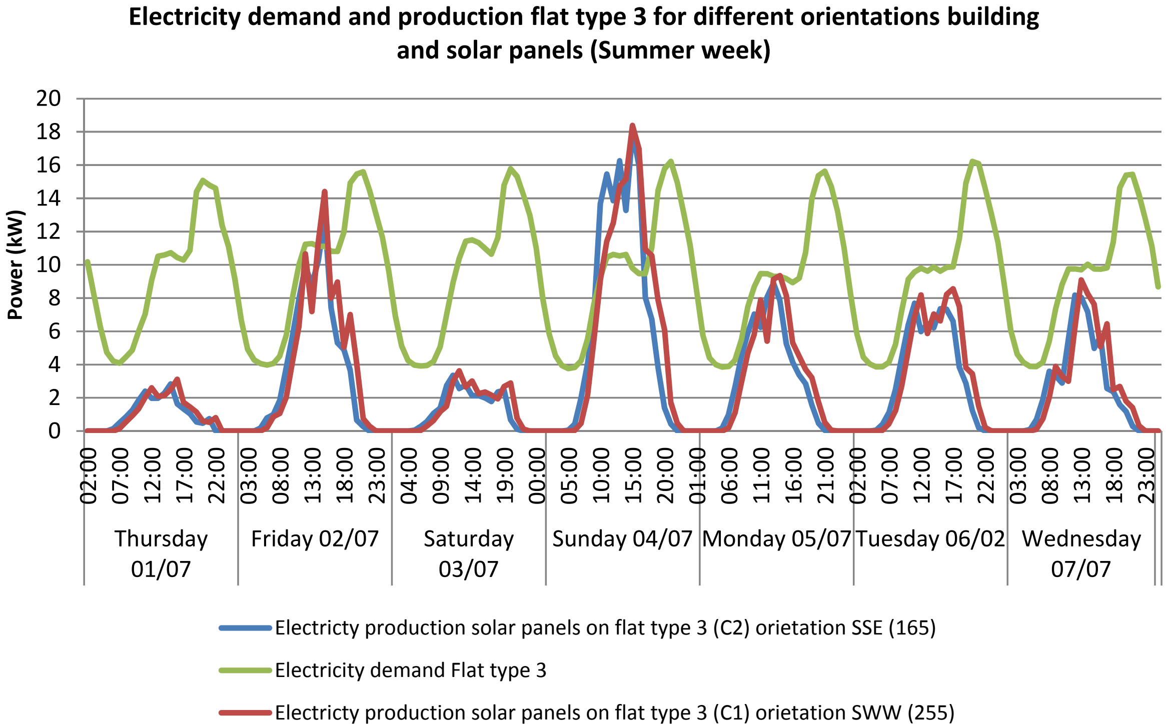

Figure 36 Electricity demand and production flat type 3 different orientations (Summer week)

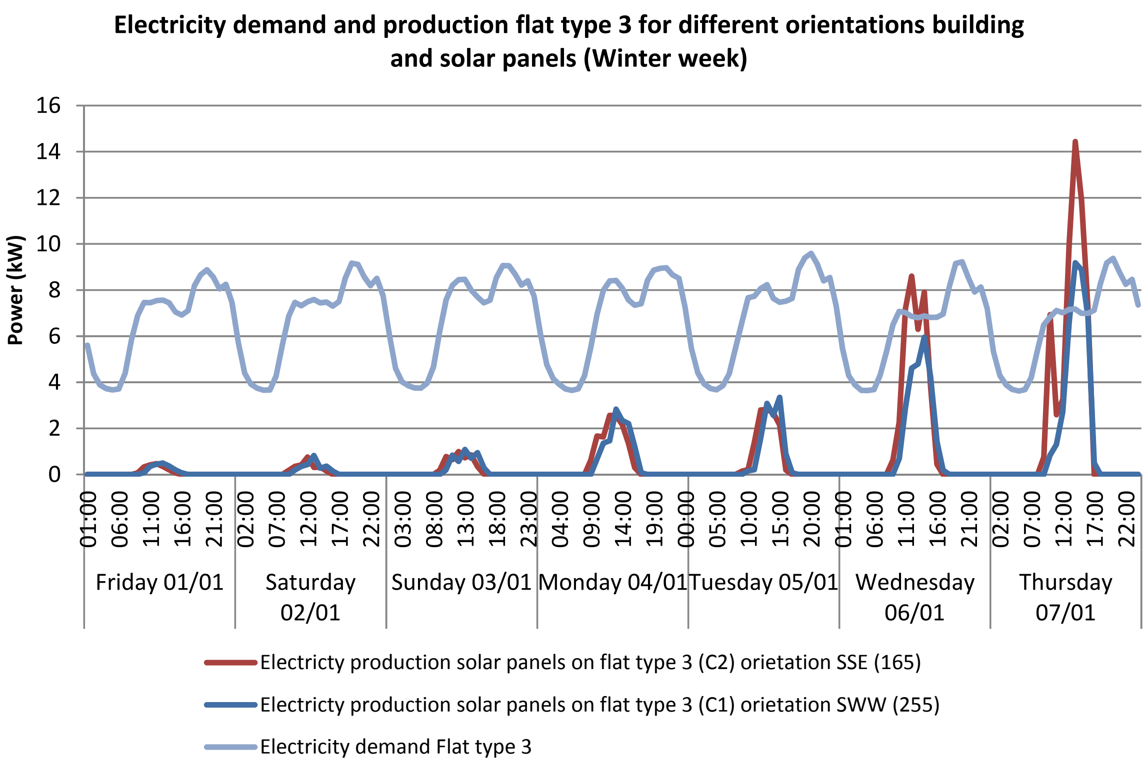

Figure 37 Electricity demand and production flat type 3 different orientations (Winter week)

Only 45% of the roof is considered as usable area to place solar panels on. The actual area that is covered with solar panels is even smaller to prevent mutual shading. To what extend a neighbourhood could produce its own energy depends on the available roof area. The Figure 38 shows the potential of electricity production when a larger area of the roof could be used.

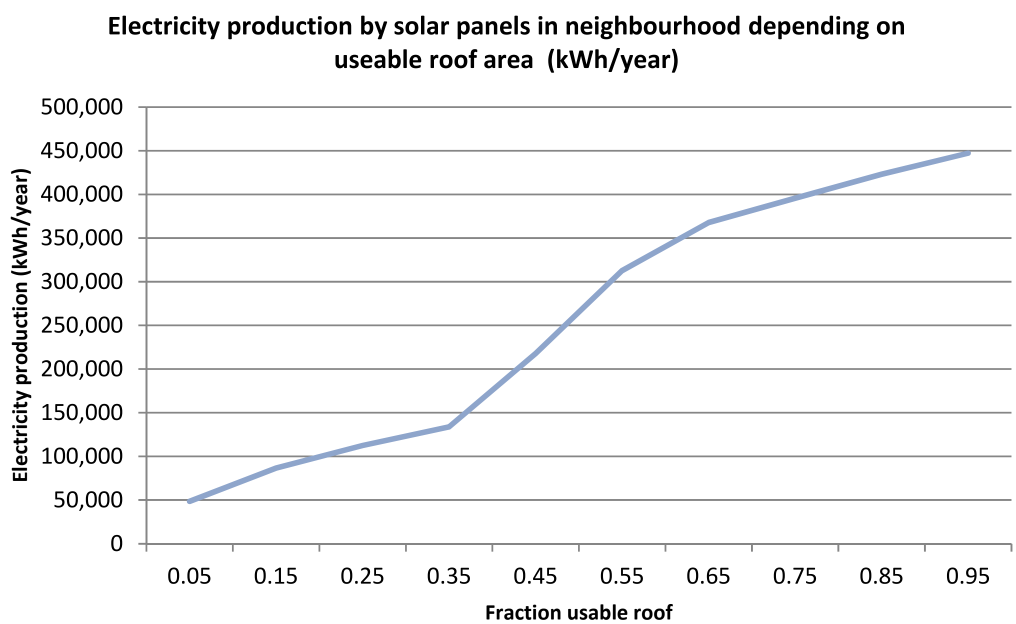

Figure 38 Electricity production by solar panels in neighbourhood usable roof area (kWh/year)

Findings electricity

In this chapter about electricity, it is described how the electricity profiles of the households are modelled. It is shown that the electricity demand could be reduced with 7% by replacing current lights with LED lights. The electricity production by solar panels is modelled with a sun simulator. The panels are installed according to the shape and orientation of the building.

6.4 Heating

6.4.1 Introduction

The buildings in the case study are currently heated with gas. A transition from gas towards an energy neutral heating technology is one of the major challenges for the Netherlands, so also in this neighbourhood. In this research a ground source heat pump is implemented. This has a great impact on the electricity profile (Hofgärtner, 2016). It increases the yearly electricity demand and could cause peak demands. The electricity demand of a heat pump depends strongly on the energy performance of a building. An alternative is to combine a heat pump with a seasonal heat storage based on thermal chemical storage. This chapter illustrates how the heating and cooling demand are related to the energy performance of the building. This is done for the current situation (gas heating) and the improved situations.

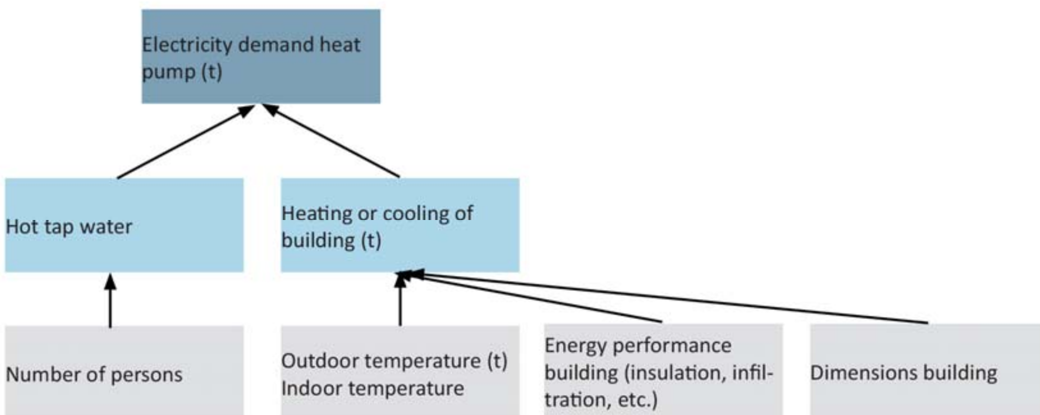

Figure 39 Concept electricity demand heat pump

6.4.2 Heat balance building

Heated volume

The buildings in the case study are modelled as one volume instead of different apartments or rooms. An apartment in the corner of the building is more exposed to the outside air than an apartment in the middle of the building. This results in a higher heating and cooling demand for this specific apartment in comparison to an apartment that is surrounded by other apartments. Although the model gives one (weighted) average heat and cooling demand for every apartment in the building, in reality this could differ among the apartments.
The building envelope is the total volume of the building including basement and staircases. The thermal envelope is the volume enclosed by insulation, which will be heated to room temperature. In this model it is assumed that the apartments in the flats are belonging to the heated volume only. The whole combined volume of the row houses is considered as heated volume.

The next assumption that has been made is that the floors of the heated volumes are touching the ground or the basement, both have a constant temperature of 10 degrees. The other parts of the heated volume, the façade and the roof, border on the outside air, with the corresponding varying air temperature.
More information about the heated volume and the dimensions can be found in annex C.

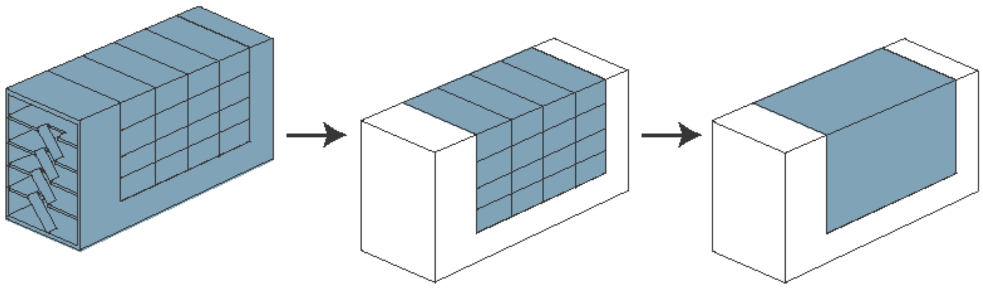

Figure 40 Concept heated volume

Design temperatures

The inside temperature is taken as 20 degrees (Itard, 2012) which is considered as a constant. In a very well insulated building this could mean that the heat pump constantly regulates the heat balance, avoiding peak demands. In a poorly insulated building, it would be more likely only to turn on the heating when some is at home due to the higher losses. By choosing a constant inside temperature, the heat demand for the buildings in the current situation might be larger than actually required.
Based on the design temperature, the energy content is calculated. All temperatures are assumed to be static, except for the ambient air temperatures (NEN 5060, 2008). The hot tap water demand needs to be heated till 60 degrees to prevent legionella bacteria (Itard, 2012). Hot water from the hot water storage tank could be mixed with cold water to achieve the 40 degrees for space heating. The focus is not on the exact modelling of the temperature differences, only rough energy balances. The ground temperature deeper than 1 meter is almost constant, resulting in a temperature of 10 degrees in the Netherlands (KNMI, 2005). A temperature of 10 degrees was also chosen in (Van Dijk et al., 2011).

$T_{in,ground}$ = ground temperature = 10 degrees Celsius
$T_{out,htw}$ = temperature hot tap water = 60 degrees Celsius
$T_{out,sh}$ = temperature space heating = 40 degrees Celsius
T_{inside} = temperature room temperature heat pump scenario = 20 degrees Celsius
$T_{inside,gas}$ = temperature room temperature gas scenario = 17 degrees Celsius
T_{amb} = temperature outside temperature (t) (NEN 5060, 2008)
$T_{in,heat\ battery}$ = temperature required to store heat in TCM battery = 80 degrees Celsius

The used distribution efficiencies, according to (Uniec 2, 2016), are shown in the Table 18. The losses of for space heating are very low due to the fact that the whole heating system is inside the thermal envelope. This is why it is not counted as loss.

Heat losses depend on the temperature difference and the length of the pipe (Itard, 2012). If a large distribution system is located outside, for example a district heating system, heat losses could reach 25% (Oosterbaan, 2016).

Distribution efficiencies	
Gas (radiators)	0.95
Heat pump (low temperature heating)	1.0
Hot water	0.742

Table 18 Distribution efficiencies

Heat balance

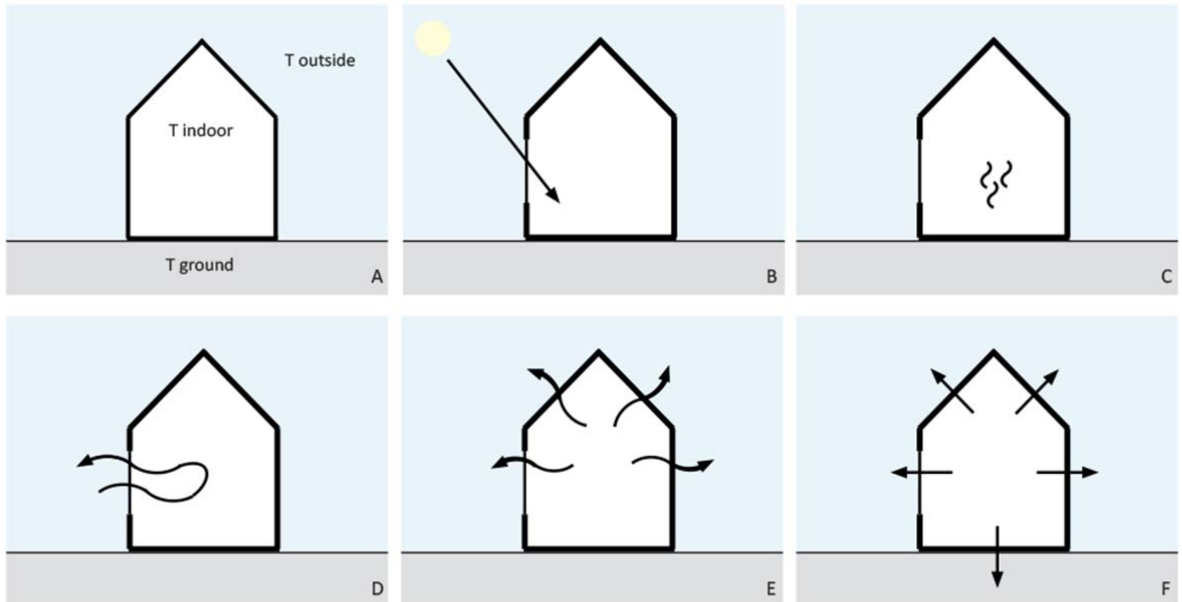

Figure 41 Concept of heat balance

The Figure 41 shows the concept of the heat balance. How much heat is transferred from indoor to outdoor depends on the air temperature inside and outside and the temperature of the ground shown in A. The concepts shown in B and C represent the heat gain. Heat gain B is the heat transferred from the sun inside the building. C shows the internal heat gain, produced by appliances, lights and people. The pictures D, E and F show the heat losses. Ventilation of buildings is necessary to provide fresh air, shown in D. Picture E shows the uncontrolled stream of air though for example cracks or small openings in the building. This is called infiltration. The heat loss due to ventilation and infiltration depends on the temperature inside and outside. The last picture F shows the heat transmission losses thought the walls, floor and roof. This depends on the temperature inside, outside and of the ground. Figure 43 and Figure 45 show the yearly losses and gains for flat type 1 and Figure 44 and Figure 46 a row house in the current and improved situation. The hourly heat balance of a row house is shown in Figure 47 and Figure 48. More figures can be found in annex D. Transmission heat losses can be reduced significantly by improvements in insulation. Also ventilation losses decreased due to the heat recovery ventilation. Small peaks area shown in the ventilation losses. On these moments no heat is recovered due to higher solar gains. In this way the outside air can be used to release some heat. The impact of each measure on the heating demand are shown in annex D. The modelling of the different parts of the heat balance are discussed in this chapter.

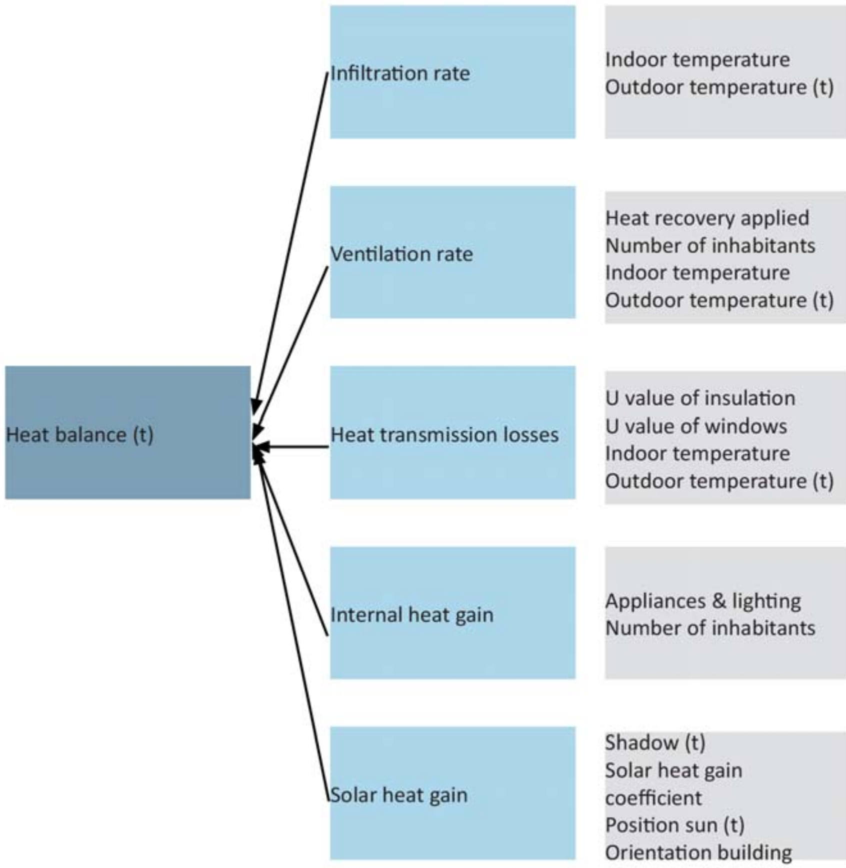

Figure 42 Heat balance model

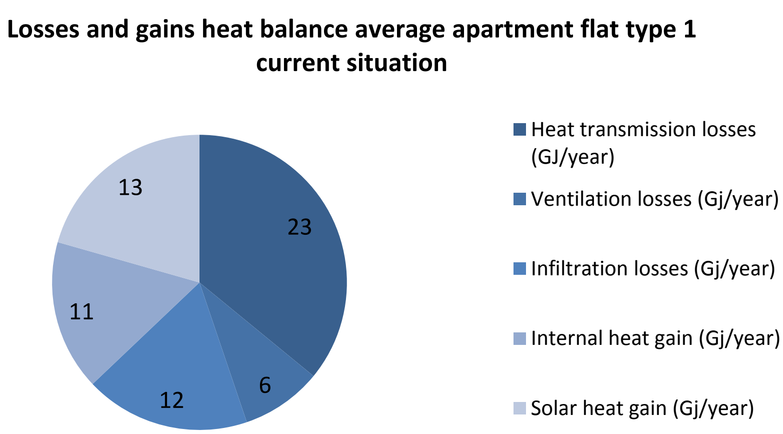

Figure 43 Yearly heat balance apartment flat type 1 current situation

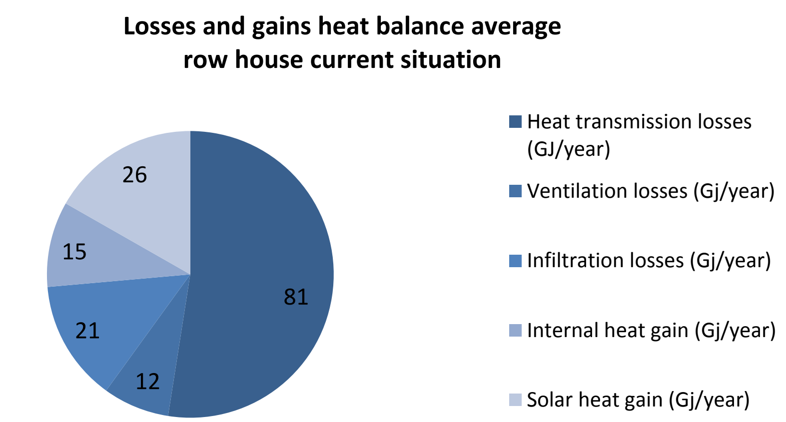

Figure 44 Yearly heat balance row house current situation

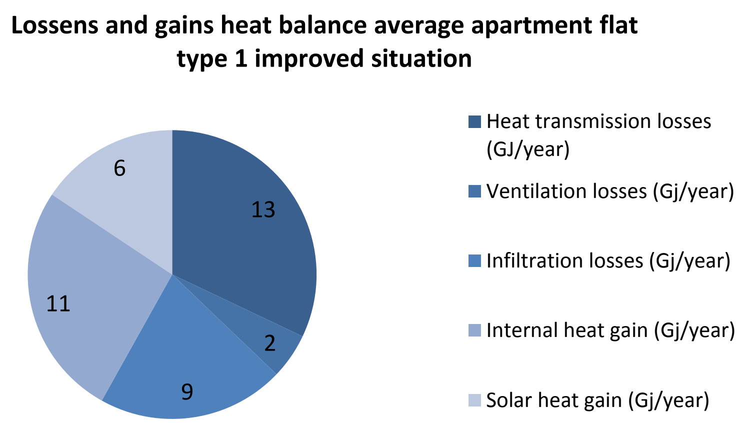

Figure 45 Yearly heat balance apartment flat type 1 improved situation

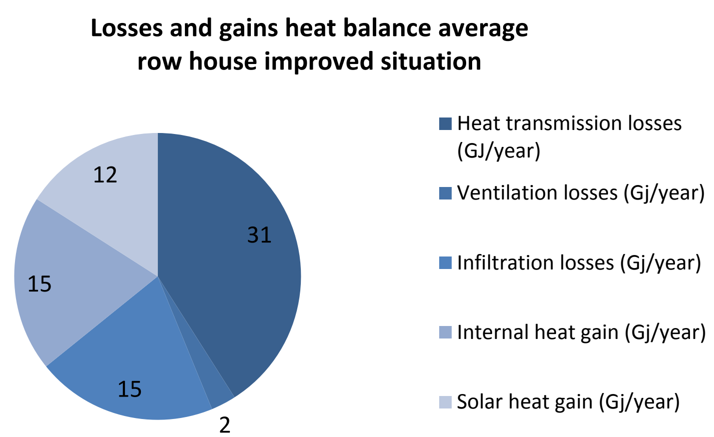

Figure 46 Yearly heat balance row house improved situation

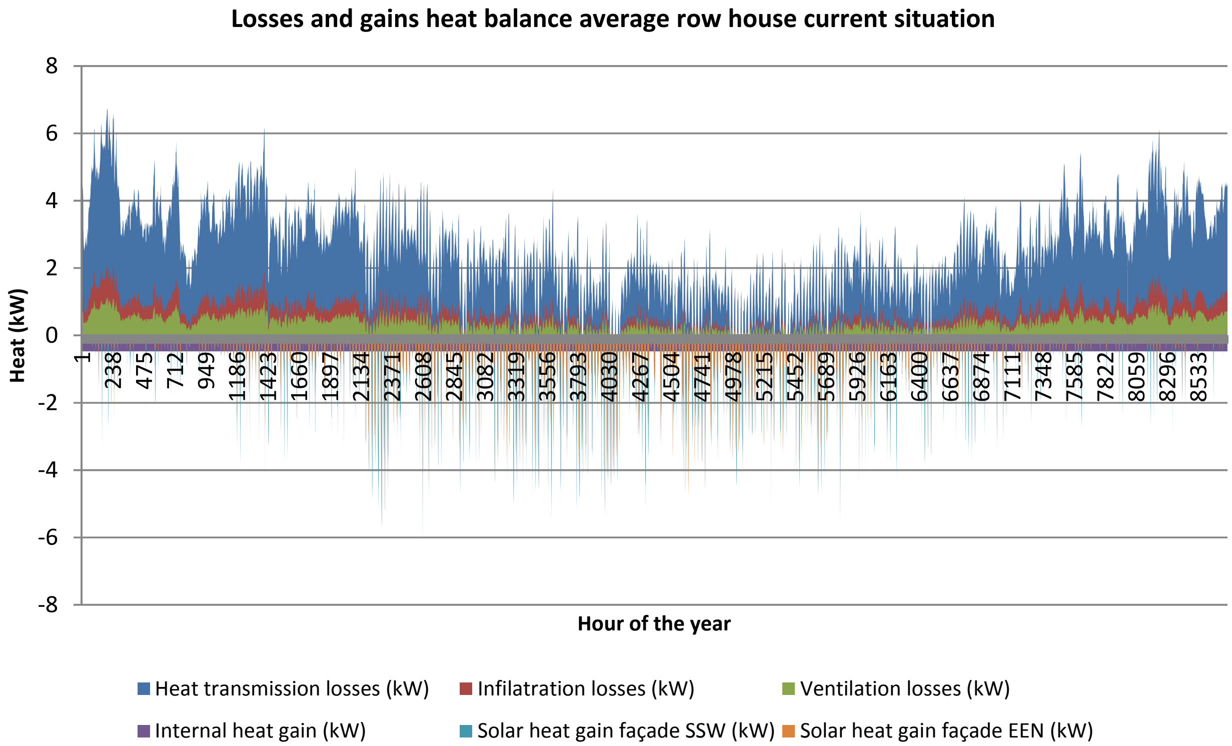

Figure 48 Losses and gains heat balance average row house current situation

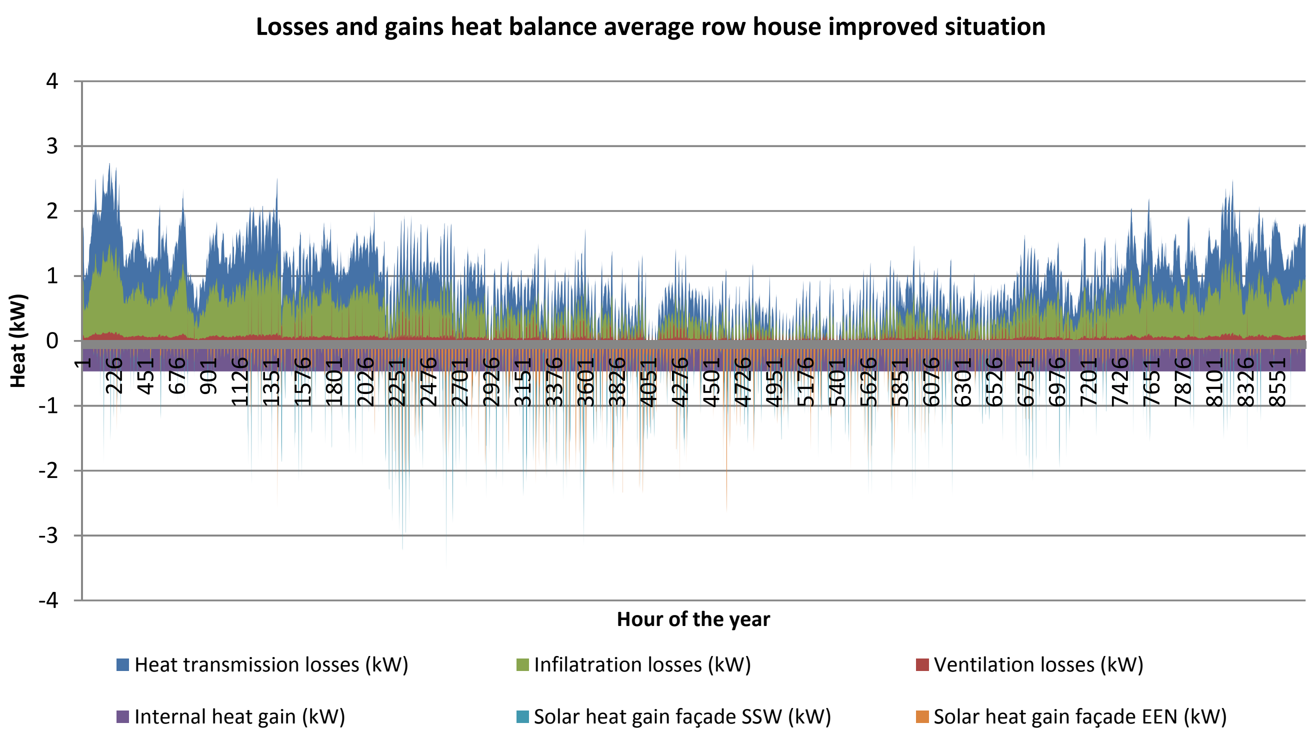

Figure 47 Losses and gains heat balance average row house improved situation

Space heating demand

Heating demand depends on the energy performance of the building and the outdoor climate, consisting of various energy flows: conduction, ventilation, infiltration, solar gains and internal gains (Itard, 2012).
The heating or cooling demand can be written as:

$$q_{balance}(t) = q_{trans}(t) + q_{infil}(t) + q_{vent}(t) + q_{intH}(t) + q_{solarG}(t) \ \text{[Wh or MJ]} \quad (8)$$

t = hourly time step
$trans$ = heat transmission
$infil$ =infiltration
$vent$ = ventilation
$intH$= internal heat
$solarG$ = solar gain

The internal heat and solar gains are negative numbers.

The heat demand per m2 of the buildings in the case study are compared with different type of buildings is shown in Figure 49 (DDG, 2016). In order to compare the heating demand with the current situation (poorly isolated) a lower average indoor temperature is used (Spiekman, 2012).
The most energy efficient building is a passive house. It has a heat demand of 15 kWh/m2 per year and a total energy use, including appliances, of (primary) 120 kWh/m2 per year (de Boer, Kondratenko, Jansen, Joosten, & Boonstra, 2009).

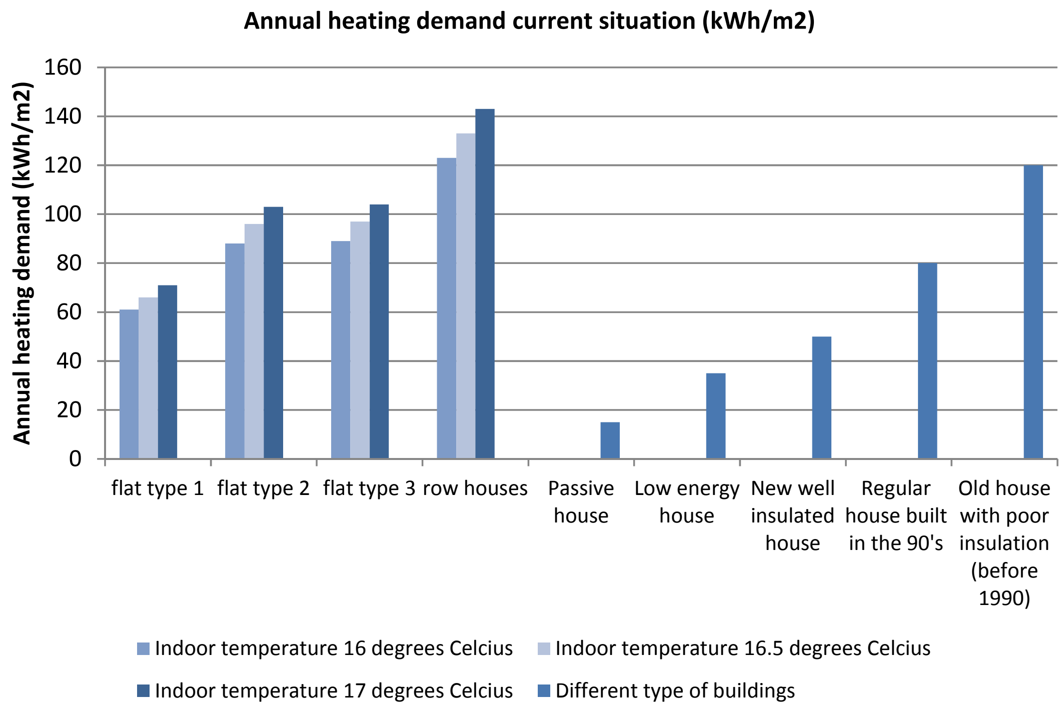

Figure 49 Annual heating demand current situation

Flat type 1 is better insulated than the other three buildings. The flats have a lower area per apartment than the Dutch average and are built very compact, flat type 1 has for example 120 apartments is one block. This could result in a lower heating demand than the presented buildings that are used as comparison.

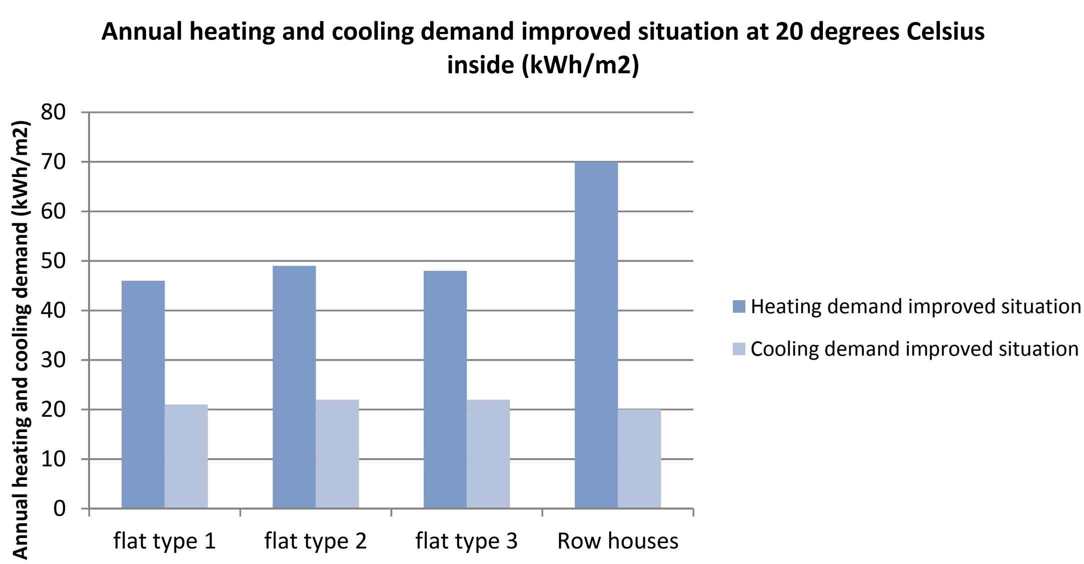

Figure 50 Annual heating and cooling demand improved situation (kWh/m2)

Heat transmission

The energy flow through the building construction, named transmission losses, depends on the temperature difference inside and outside of the building and the heat transmission coefficient U of the walls, floors and roofs.

$$P_{trans} = A \cdot U \cdot (T_{in} - T_{out}) \text{ [W]} \quad (9)$$

U = heat transfer coefficient $[W/(m^2 \cdot K)]$
A= area surface $[m^2]$
T_{in} = room temperature
T_{amb} = outside temperature

Modelling thermal bridges become more important in a building with a high energy performance. This loss could be as high 10-15% (Itard, 2012). For this research the thermal losses are not considered. Further research on a more detailed level will be necessary to minimize energy loss through thermal bridges in the improved situation.
The quality of insulation in the current and the improved situation are shown in the table below. The heat transmission coefficients in the current situation were estimated in the (Hofgärtner, 2016), the values for the improved situation are standards for deep renovation of buildings. The maximum U-value for the windows are 1.65 (W/m^{2}k). The maximum standards for roofs, facades and floor are between 0.17 and 0.29 (W/m^{2}k) depending on which part of the building (RVO, 2016). In this research no difference was made between the floor, façade and roof.

	Current situation (Hofgärtner, 2016)				Improvement
Building	**Flat type 1**	**Flat type 2**	**Flat type 3**	**Row houses**	**All buildings**
U-roof (W/m^{2}k)	0.5	1.12	1.12	1.12	0.21
U-façade (W/m^{2}k)	0.47	0.68	0.68	0.68	0.21
U-floor (W/m^{2}k)	0.52	1.22	1.22	1.22	0.22
U window (W/m^{2}k)	2.9	2.9	2.9	2.9	1.4

Table 19 Energy performance

According to (Itard, 2012), the thermal mass does not influence the heating demand significantly; buildings with heavy thermal mass are exceptional. Nevertheless, it has significant influence on the cooling demand. A building with a high thermal mass can store the heat gained by solar radiation and releases it during the night which could reduce the cooling load. The buildings in the case study don't have significant thermal mass, therefore the effect of thermal mass on the heating demand is not considered. The cooling demand is minor in the current situation. The cooling can be provided with the heat pump in the improved situation. Possible savings in cooling due to the thermal mass are not included in this research. More detailed modelling of the energy performance of the buildings will be necessary to estimate this effect. In this research, the energy required for cooling is relatively small compared to the overall energy use of, for example, an office building. On top of that, the ground that is used to extract heat in winter with a heat pump, needs to be used for cooling in summer as well to keep the source in balance.

Ventilation

Ventilating the buildings is necessary to provide the rooms with fresh air. In winter this could result in a heat loss because air at room temperature is extracted and outside air is used as inlet. One way to reduce the energy loss is by installing a ventilation system with heat recovery. Via a heat exchanger the heat can be recovered during winter (or cool air in summer) which could save up to 90% of the heat demand (Itard, 2012).

$$P_{vent} = (1 - ή) \cdot C_{air} \cdot \rho_{air} \cdot V_{rate} \cdot (T_{in} - T_{out})[W] \quad (10)$$

ή = heat recovery rate = 0.9
V_{rate} = ventilation rate $m^3/h\ \ pp$
T_{in} = room temperature
T_{out} = outside temperature

A ventilation rate of 25-50 m3 per person is required (Itard, 2012). However, in residential houses with a high infiltration rate, ventilation is only limited necessary. A higher ventilation rate is applied in the improved situation to ensure enough air change since the infiltration rate is smaller.

Situation	Current	Improved
Building	all	all
Ventilation rate per person (m3/hour)	40	50
Heat recovery (ή)	-	0.9

Table 20 Ventilation rates

If ventilation is combined with heat recovery, the recovery rate can be adjusted. This way the outside temperature can be used to heat or cool the building inside. For example, if the outside temperature is warmer than inside and heating is required, the recovery rate can be zero. In this way, the outside air is used to heat up the inside air.

Without heat recovery ventilation:

Heating

$$q_{balance}(t) > 0 \quad (11)$$

Cooling

$$q_{balance}(t) < 0 \quad (12)$$

Energy conservation

$$q_{balance}(t) = 0 \quad (13)$$

With heat recovery ventilation the energy loss due to ventilation is:

$$q_{vent}(\mathrm{t}) = q_{out,conv}(\mathrm{t}) = (1\text{-}ή) \cdot C_{air} \cdot \rho_{air} \cdot V_{rate} \cdot (T_{in} - T_{out}(\mathrm{t})) \quad (14)$$

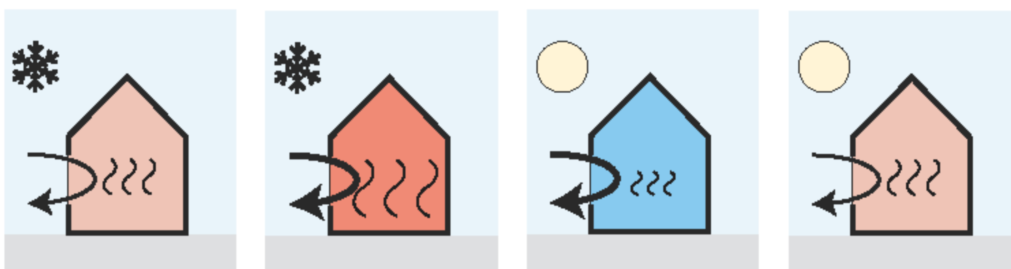

Figure 51: Concept heat recovery ventilation. The heat recovery is regulated according to the indoor and outdoor climate.

Whether the heat recovery is turned on depends on the energy balance and the temperature outdoor.

Heating

$$(q_{trans}(\mathrm{t}) + q_{infil}(\mathrm{t}) + q_{intH}(\mathrm{t}) + q_{solarG}(\mathrm{t}) > 0) \cap (T_{amb} < T_{in}) \rightarrow ή = 0.9 \quad (15)$$

$$(q_{trans}(\mathrm{t}) + q_{infil}(\mathrm{t}) + q_{intH}(\mathrm{t}) + q_{solarG}(\mathrm{t}) > 0) \cap (T_{amb} > T_{in}) \rightarrow ή = 0 \quad (16)$$

Cooling

$$(q_{trans}(\mathrm{t}) + q_{infil}(\mathrm{t}) + q_{intH}(\mathrm{t}) + q_{solarG}(\mathrm{t}) < 0) \cap (T_{amb} < T_{in}) \rightarrow ή = 0 \quad (17)$$

$$(q_{trans}(\mathrm{t}) + q_{infil}(\mathrm{t}) + q_{intH}(\mathrm{t}) + q_{solarG}(\mathrm{t}) < 0) \cap (T_{amb} > T_{in}) \rightarrow ή = 0.9 \quad (18)$$

ή = heat recovery rate

Infiltration

Infiltration is an uncontrolled stream of air through small openings in the building, which is very hard to calculate exactly. The amount of heat that is lost due to infiltration depends on the air tightness of the building.

$$P_{out,infl} = C_{air} \cdot \rho_{air} \cdot V_{building} \cdot n \cdot (T_{in} - T_{out}) \quad [W\} \tag{19}$$

$V_{building}$ = volume building [m3]
n = air change per hour
T_{in} = room temperature
T_{out} = outside temperature

Situation	Current	Improved
Building	all	all
Air change per hour ($V_{building}$/hour)	0.55	0.4

Table 21 Infiltration rates

Typical air change rates per hour (n) are for (Itard, 2012)
New large air tight buildings: 0.1-0.2
Smaller buildings: 0.2-0.3
Old buildings: 0.5-1

Internal gains

Heat is produced by people, appliances and lights present in the building. The amount of people and their physical activity have influence on the heat production inside. Typical heat productions are ranging from 100 watt per person for a sitting or resting person, 180 watt for a person that is walking or cooking till 360 watt for someone who is dancing (Itard, 2012). In this model the average heat production per person is assumed at 100 watt per inhabitant. Variations, like the number of persons and their activity, are not taken into account. In (Van Dijk et al., 2011), the internal gains by persons are calculated with an average heat production of 100 watt per person and the person is present during 45% of the time. This is modelled as constant 45 watt per person per apartment.

According to (Itard, 2012) most of the electricity that is used by appliances and light is released as heat. Therefore, the total power of light and electricity is assumed to be an internal heat gain. Typical electrical power needed by appliances for residential buildings is around 5 W/m2 (Itard, 2012). The maximal allowable lighting for a residential function is 10 W/m2 (Itard, 2012). Summing up the internal gain by lighting and appliances results in 15 W/m2. This would be a very large number since these are not constantly turned on.

In (Van Dijk et al., 2011), the internal gains by lighting and appliances are estimated for a house of 105 m2. This resulted in a constant internal heat production of 4 w/m2. This is value is used in the model for the flats. A lower value is used for the row houses due to their larger area.
More detailed data of installed lighting and appliances would be needed to make a more realistic estimation of internal gains.
The total internal gains consist of the number of inhabitants, installed lighting and appliances:

$$P_{intH} = P_{int,persons} + P_{int,lighting} + P_{int,appliances} \text{ [W]} \quad (20)$$

Situation	all	all
Building	Flats	Row houses
Heat person (W/p.p)	40	50
Heat light + appliances (W/m2)	4	3

Table 22 Internal heat gain

Solar gains

The sun transmits heat through the windows which heats up the building. The amount of heat depends on the position of the sun, the surface of the windows, the reflection of the window, and the shadows casted by surrounded objects such as other buildings, trees or sheds. All factors depend on the orientation with respect to the position of the sun (Itard, 2012):

$$P_{solarG} = (A_{windows} \cdot I_{glob} \cdot g_{glass} \cdot g_{shadefactor})_i \text{ [W]} \quad (21)$$

$g_{shadefactor}$ = shade factor
$A_{windows}$= area windows [m2]
$I_{glob}(t)$ = global radiation [W/m2]
Dependent on orientation $_i$

The reflectiveness of the windows could be different for direct and diffuse radiation. A simplification was made by assuming that the reflectiveness is the same for all angles of incidences.
The solar heat gain coefficient of a double glazed window which is uncoated is around 0.7, for triple glazing around 0.5 (Itard, 2012). The first factor is taken for the current situation, the second factor for the improved situation.

The typology of the neighbourhood, including building height and the distance between the buildings, influences the shadow casting within the neighbourhood. The shadow casted on the buildings doesn’t only influence the heat balance but also the energy production by solar panels.

The shadow factors are manually estimated from a sketchup 3D model of each façade with windows and each roof. 14th of the month is chosen as representative day of the month. In December the sun is the lowest, in June the highest. The values found in January are used in November, the values from February are used in October etc. The factors represent the percentage of the total façade or roof that is covered with shadow casted by surrounded buildings.
This is multiplied by an additional factor of 0.8 for g shade to compensate other shadows for example from the façade of the building itself. It has to be noticed that this factor is not time dependent. In further research, more detailed shadow modelling could be taken into account. For example, shadows by trees or the form of the façade.
Finally, an additional louvre or roller shade is added to the window in the improved situation. In a well-insulated, overheating has to be prevented. This factor only applies when outside is more than 12 degrees Celsius.

Situation	Current	Improved
Building	All	All
Solar heat gain window	0.7	0.5
Shadow factor (t)	Dependent on building	Dependent on building
Additional shadow factor	0.8	0.8
Louvre or roller shade (T_{out} > 12 degrees Celsius)		0.6

Table 23 Sun heat gain and shadow factors

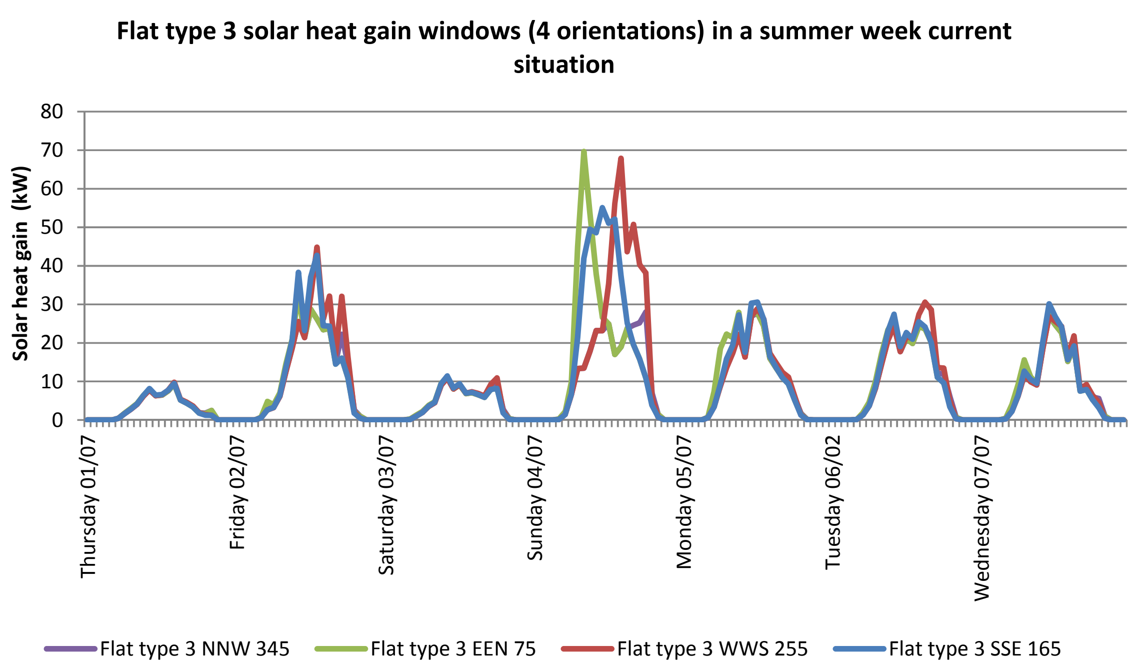

Table 24 Flat type 3 solar heat gain windows (4 orientations) in a summer week

Hot tap water demand

The total heating demand consists of space heating and hot tap water. While space heating strongly depends on the weather outside, it is assumed that hot water demand is not varying during the year, only during the day. (Itard, 2012) estimates a hot water demand of 130-160 litre per day per dwelling in USA. In this research it is assumed that the hot water demand is 40 litres per person per day. A similar number was found in (Van Dijk et al., 2011). Here it was mentioned that the average hot tap water demand in the Netherlands is 37 litres per person per day.

$$P_{in,htw} = C_{water} \cdot \rho_{water} \cdot \mathrm{V_{htw}} \cdot (T_{htw} - T_{out,ground}) \text{ [W]} \quad (22)$$

$\mathrm{V_{htw}}$ = hot tap water demand [litres/hour]
$T_{out,htw}$ = temperature hot tap water = 60 degrees Celsius
$T_{in,ground}$ = ground temperature = 10 degrees Celsius

6.4.3 Gas heating

System losses

Storing and transporting hot water will involve losses. The following losses are assumed in this research. These efficiencies were found with the help of the program (Uniec 2, 2016). As described in (Hofgärtner, 2016) flat type 3 produces hot tap water with a geyser. It is chosen to model with the same energy system flat type 2 in order to keep it simple. Also the current gas use of flat type 2 is used, which is higher than with a geyser. These buildings have the same building quality and nearly the same dimensions.

Production efficiency	Flat type 1	Flat type 2	Flat type 3	Row houses
Heating & hot water system	Individual HR combination kettle	Collective combi HR kettle	Collective combi HR kettle	Individual HR combination kettle
Efficiency production space heating	0.95	0.9	0.9	0.95
Efficiency production hot tap water	0.85	0.9	0.9	0.85
Additional losses for collective system hot tap water		0.6	0.6	

Table 25 Heat production efficiency per case study

The standard efficiency of the hot tap water production by individual HR kettle is 67.5%. When selecting an installation that is available on the market, a higher efficiency can be found of 80% and up to 85% (Van Oeffelen & Van Wolferen, 2012).
Circulation efficiencies can range from 40% for uninsulated pipes to 70% insulated pipes. In this research 60% is taken. This is only applied to the buildings with a collective hot tap water system.

Figure 52 shows the yearly gas use of the different type of buildings. As described in (Hofgärtner, 2016) flat type 1 has reliable gas use data due to the high number of apartments. The gas consumption data of the other three types are highly uncertain due to missing and invalid data values. Therefore, the gas use of flat type 1 is used to level the model. The gas demand of the row houses is higher than in the case study. This could be explained by the fact that the attic floor is taken into account as heated volume in the model but not actively used in most of the row houses. Just a few of the row houses have a dormer window. The Figure 52 shows how the yearly gas consumption is dependent of the desired indoor temperature. An average indoor temperature of 17 degrees Celsius is used for modelling poorly insulated buildings (Spiekman, 2012).
In the continuation of this research, the heat balance of the current situation is modelled with an inside temperature of 20 ^{o}C.

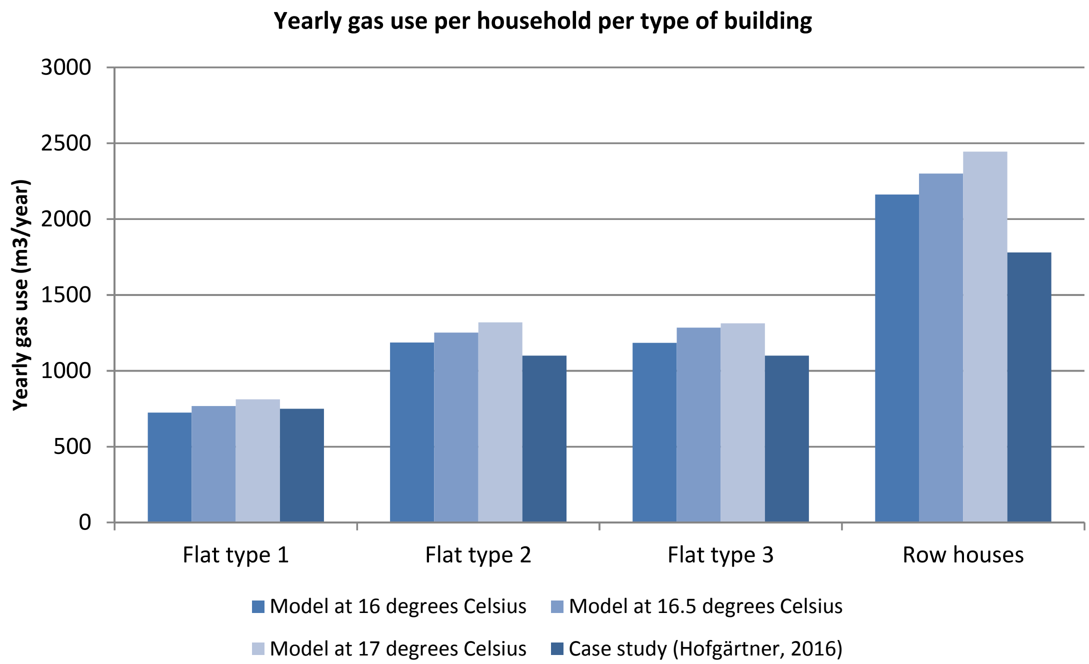

Figure 52 Yearly gas use per household per type of building

The Dutch average gas use for hot tap water is 280 m3 (Milieucentraal, 2016a). The row houses and flat type 2 and 3 show a very comparable result, shown in Figure 53. As described in (Hofgärtner, 2016) the row houses in this case study shows many similarities compared to average Dutch data. In contrary, flat type 2 and 3 have a relatively high hot water demand. This is due to the collective hot water system which involves many losses.

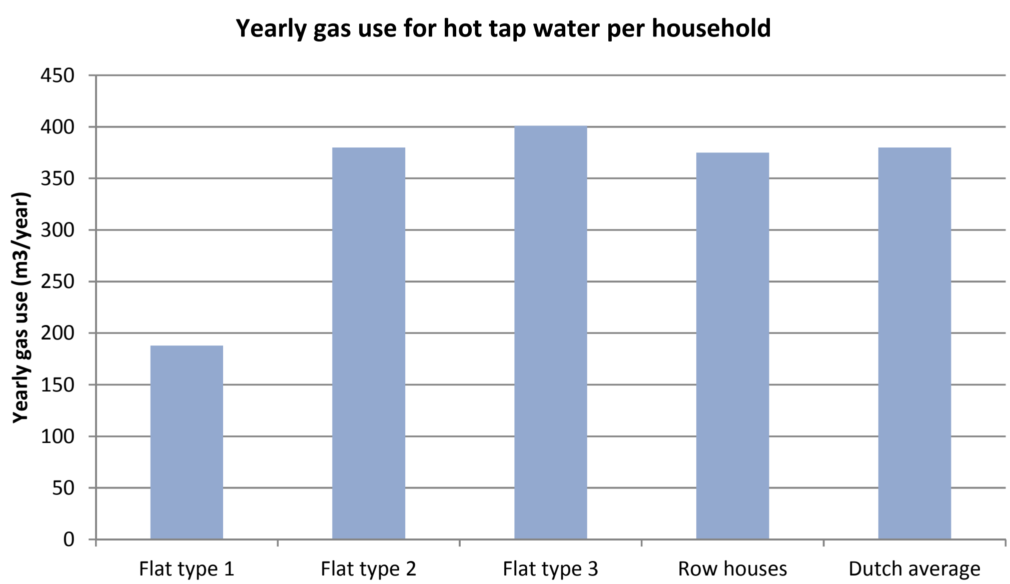

Figure 53 Yearly gas use for hot tap water per household

6.4.4 Heat pump

System design

Distribution losses of hot tap water can be reduced by producing hot water close to the place where it is used. Therefore in the (Hofgärtner, 2016) it was proposed to install a separate booster heat pump and hot water storage tank in each apartments of the flat for hot tap water only. The remaining installations can be placed in the basement; the heat pump for space heating, the heat battery and if necessary a reserve hot water tank.

Heat pump

A ground source heat pump is chosen to fulfil the heating and cooling demand. It uses the constant temperature of the ground to preheat or precool the water.
An advantage of the ground source heat pump is that even if the outside temperatures are low, the ground will supply relatively constant heat. An air heat pump is easier to install, but could lead to higher electricity demand in cold periods, since it uses the ambient air as inlet (EnerGuide, 2004).
A heat pump can be used for low temperature space heating and for hot tap water. Hot tap water requires a higher temperature that will increase electricity demand. The performance of a heat pump can be expressed in COP, coefficient of performance (B. Asare-Bediako, Kling, & Ribeiro, 2014)

$$\mathrm{COP} = \mathrm{Heat\ balance\ (t)/\ electrical\ energy\ output\ (t)} \qquad (23)$$

The COP of the heat pump are different for heating, cooling and hot tap water.
COP = 3 for cooling
COP = 5 heat production
COP = 3 hot tap water production

Hot tap water demand has a fluctuating profile during the day. In this research it is assumed that hot water could be stored in a hot water tank and takes care of the hot water demand. The hot water tank needs a minimum amount of energy in the tank, which is equal to the hot tap water demand of one day. In this way, it doesn't matter for the model whether all hot water is used in one hour or equally spread over the whole day. The heat required to heat the tap water is modelled as a constant load. It is assumed that the hot water tank is very well insulated and had not losses.
In (Uniec 2, 2016) the COP of hot water production is around 1.4 till 2.8. In this research a separate booster heat pump is used (Itho, 2016). The advantage is that it uses the return temperature of the space heating or solar boiler instead of heating water of 10 degrees to 60 degrees. This temperature ranges between 15-40 ^{o}C. Depending on the temperature that is used as inlet the COP of the booster heat pump is between 2.2 and 3.76, when heating the water till 60 degrees. In this research the return temperature of space heating is minimal 20

degrees (since the room temperature is required to be 20 degrees), resulting in a minimal COP of 2.67. Therefore, it is assumed that the average COP of the booster heat pump is 3. Tin for hot water is assumed to be 22 degrees.

The COP is assumed to be constant during the year. When modelling the operation of a heat pump into more detail, the COP changes because the ground source changes in temperature during the heating season or cooling season. The COP is higher at the beginning of for example the heating season, at the end of this season, the temperature decreases, leading to a lower COP.

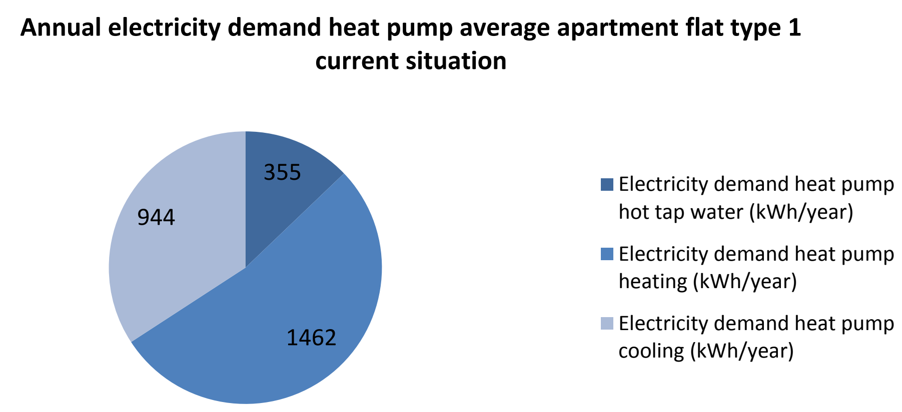

Figure 54 Annual electricity demand heat pump average apartment flat type 1 current situation

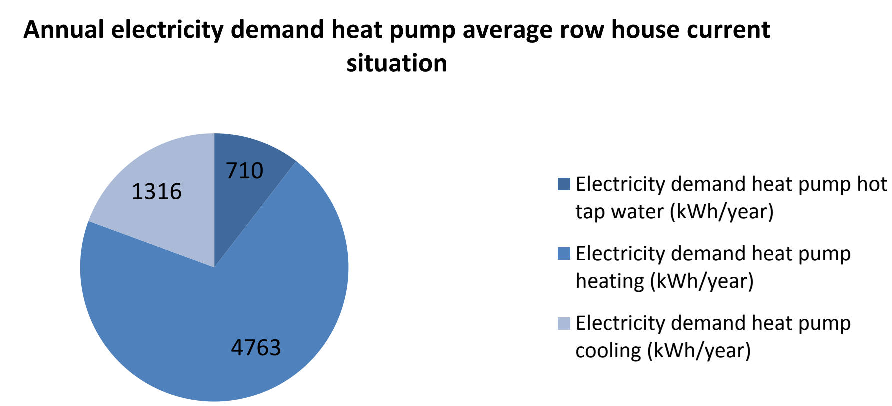

Figure 55 Annual electricity demand heat pump average row house current situation

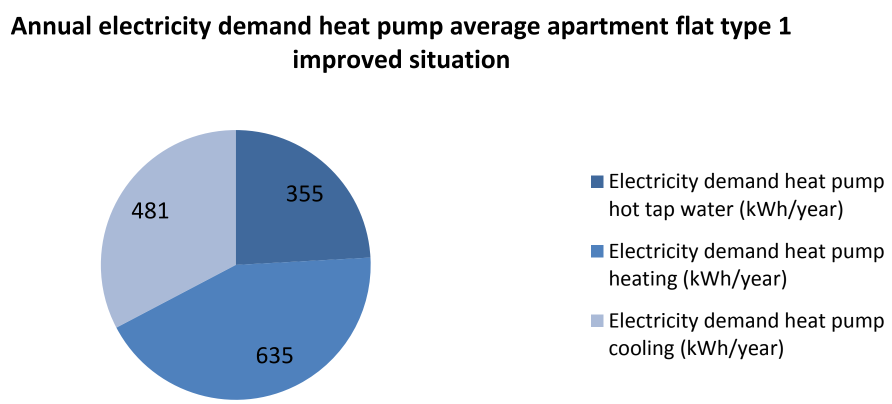

Figure 56 Annual electricity demand heat pump average apartment flat type 1 improved situation

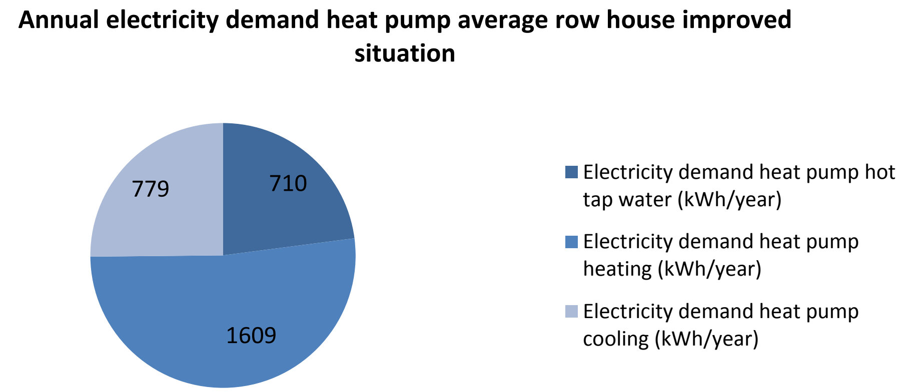

Figure 57 Annual electricity demand heat pump average row house improved situation

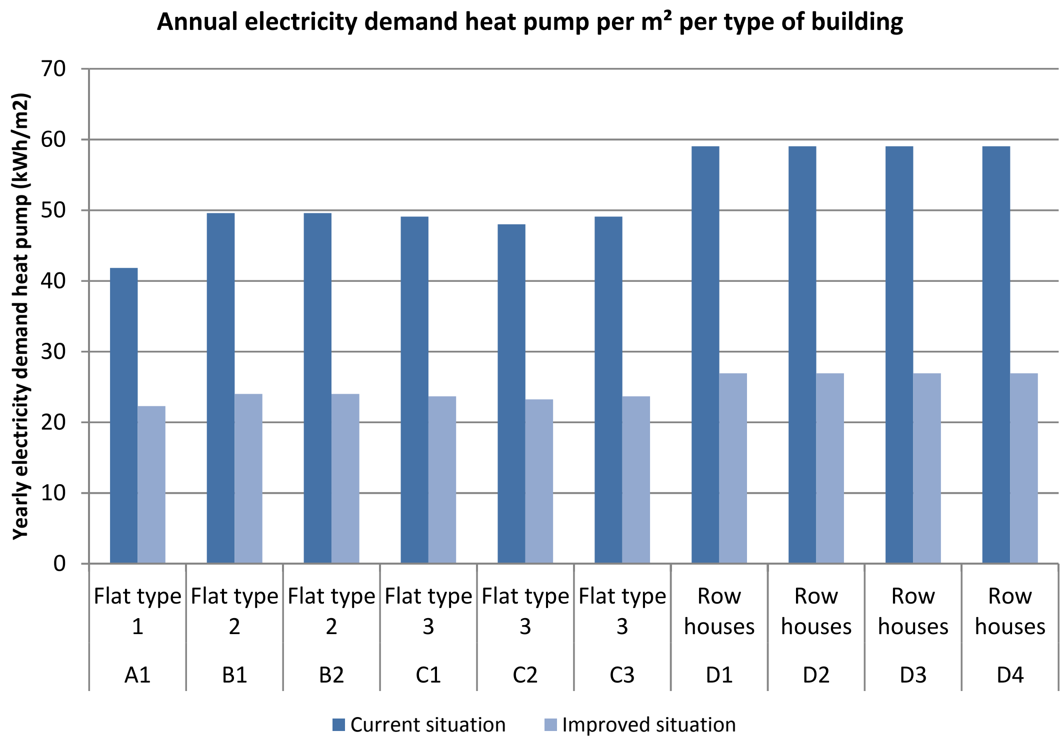

Figure 58 Annual electricity demand heat pump per m²per type of building

Although the annual cooling demand is lower than the heating demand, it has larger peak demands. This is due to the lower COP. Figure 62 shows that the operation of the heat pump is not fully optimized. In summer, it is cooling on day time and heating during the night. This is to maintain the indoor temperature at 20 degrees C. The peaks demands for cooling could be lowered if the indoor temperature would be 24 degrees C in summer (Itard, 2012). The impact of each measure on the electricity demand of the heat pump is shown in annex D.

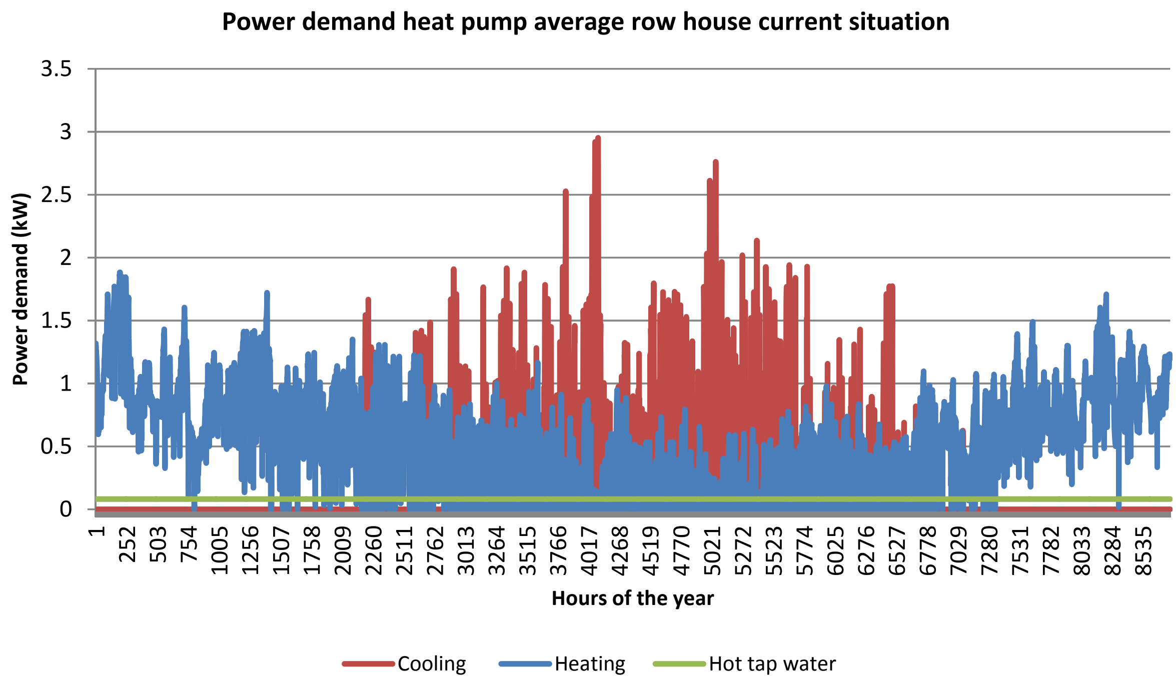

Figure 59 Power demand heat pump average row house current situation

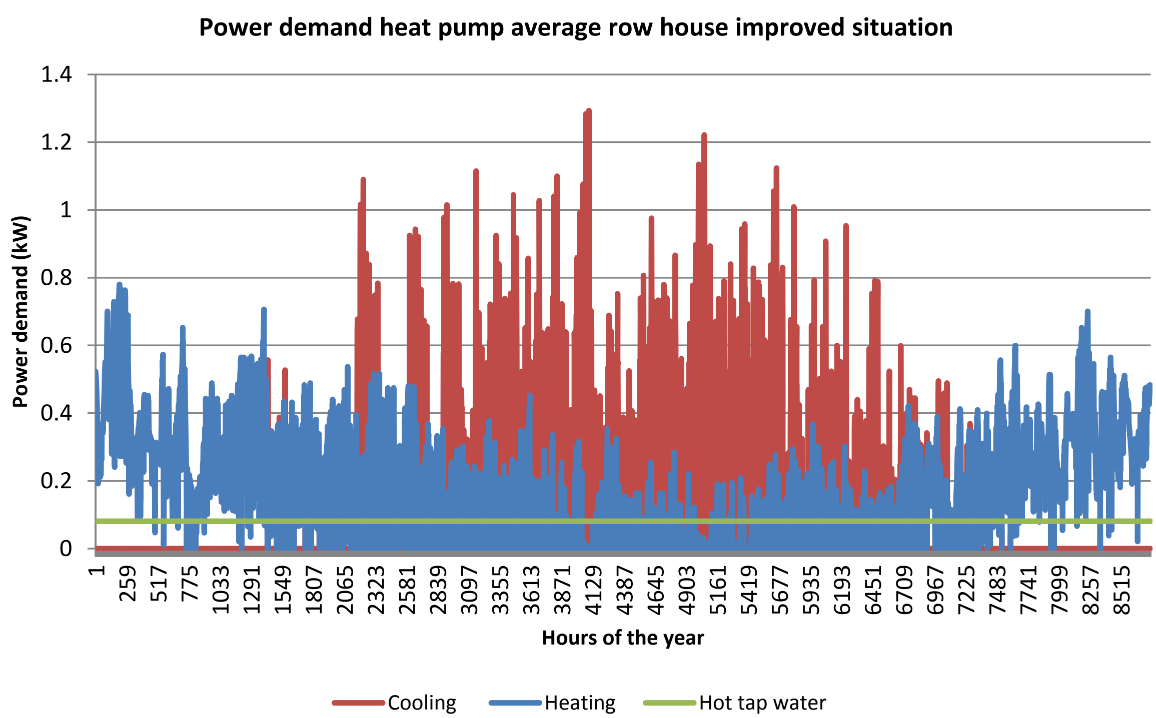

Figure 60 Power demand heat pump average row house improved situation

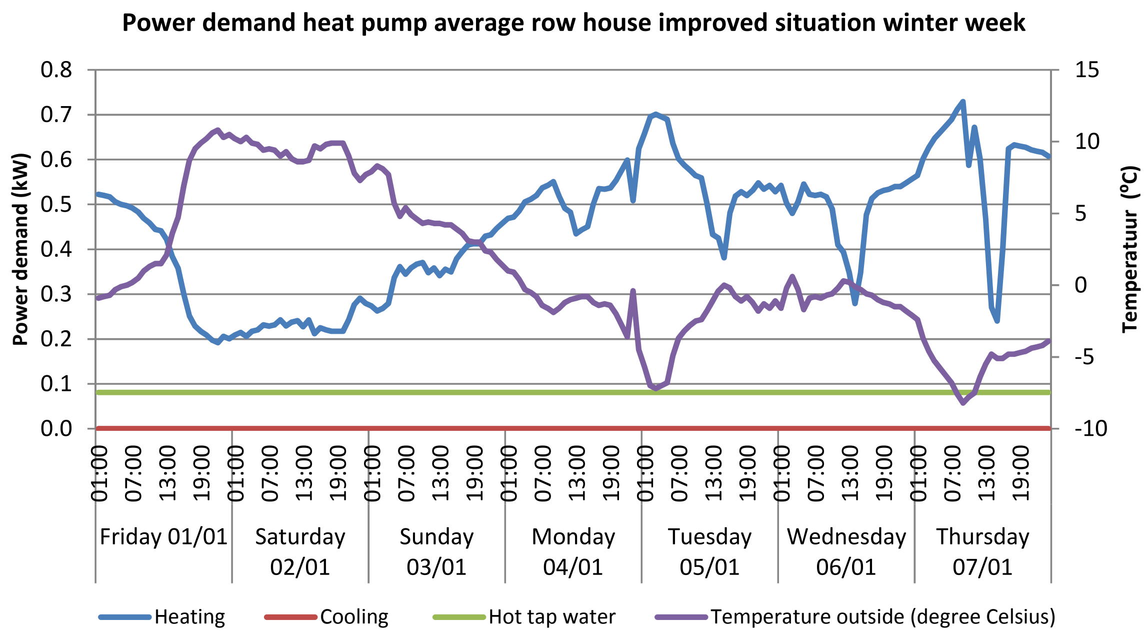

Figure 61 Power demand heat pump average row house improved situation winter week

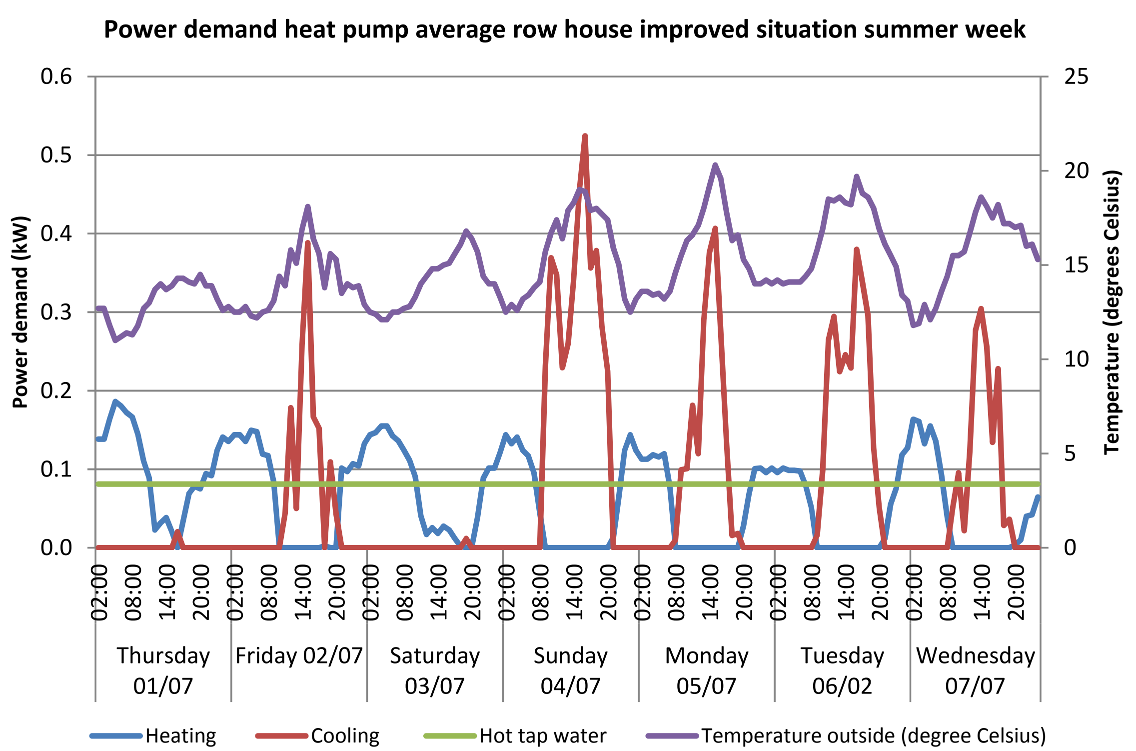

Figure 62 Power demand heat pump average row house improved situation summer week

6.4.5 Heat battery

A thermal chemical heat battery can be used as seasonal storage. For example, the heat that is produced in summer by a solar boiler, could be stored in TCM with NA2S (Ard-Jan de Jong et al., 2016). This heat can be released in winter, when the intensity of the sun is lower. A huge advantage is that there are no thermal losses during the storage. On top of that, TCM has a significant higher energy density, of 2.9 GJ/m3, compared to water at 0.2 GJ/m3 (with 50 ^{o}C difference). Heat storage with TCM requires more space than only the hydrated salt, namely: tubing, heat exchangers, vessel, etc. Including additional components, it is aimed in the research carried out by TNO to optimize the whole system to 1.0 GJ/m3. Current results show that an energy density of 0.14 GJ/m3 can be achieved (Ard-Jan de Jong et al., 2016). An energy density of 1 GJ/m3 is used in this model.

Thermal chemical storage can be used to store heat in a reverse chemical reaction and a sorption process (Fopah Lele, 2016). The material NA2S has an advantageous energy density and operation temperature (Keizers, H., personal communication, December 2016).

The thermal chemical reaction is (Ard-Jan de Jong et al., 2016):

$$Na_2S * ½\, H_2O \; + \; 4½H_2O \; \leftrightarrow \; Na_2S * 5H_2O \; + \; heat \qquad (24)$$

The heat produced by the solar boiler in the summer, can be used to separate the water and the salt by evaporation of water. The water condenses again in the water tank. In this way energy is stored, the process is called dehydration. In winter, water can be added to the salt, the water evaporates and heat is released to the hot water storage tank, called hydration (TNO, 2016).

A fixed TCM bed is used in combination with a vacuum, closed system. There are three advantages of a vacuum system. First, the process of evaporation and the penetration of the water vapour in the salt crystals happens fast. Second, no additional energy is needed to activate the heat battery to release heat. Evaporation (boiling) starts at strongly reduced temperatures under vacuum conditions and low temperature heat can be extracted from the environment. Thirdly, the closed loop prevents any contamination to be introduced into or coming out of the system, without being noticed, resulting on a long lifetime and safely operating system (Keizers, H., personal communication, December 2016).

When heat has been released from the battery, the water needs to be cooled down to 10 degrees again. If the heat battery is placed in the basement, the temperature of the ground can be used which doesn't require additional energy (Keizers, H., personal communication, December 2016). A modular system is applied to the heat battery. For example, in (Jong et al., 2014) the system consists of 100 modules, 100 MJ each. This makes it possible to release or store heat in one module, without turning on the whole system. The modules are independent from each other; when one module is used, it is not necessary to use the next module straight afterwards. Furthermore, a modular system allows varying the number of modules according to the available space and size of the heating system. It will require more space because each module needs a separate heat exchanger (Ard-Jan de Jong et al., 2016).

The water needs to have a temperature of 80 degrees to charge the battery. Therefore, the heat delivered by the solar boiler is directly delivered to the heat battery, instead of going to the hot water tank first. The hot water tank has a temperature of 60-65 degrees which is not enough for the heat battery (Keizers, H., personal communication, December 2016).
Although there are no thermal losses during the storage, there are losses when releasing the heat. This is assumed to be 10%, based on measurements on the current system (Keizers, H., personal communication, December 2016). Additionally, there are distribution losses, described before.

Solar boiler

A solar boiler can capture heat of the sun and provide a part of the hot water or space heating demand. In most cases in a cold climate, this is combined with a second heating system (Itard, 2012).
The solar boiler ATAG CBSolar 120 /1.6 was chosen, found in (Uniec 2, 2016). It has the same size, 1.6 m2, as a solar panel. The heat that is produced by the solar boiler and actually contributing to the hot water demand, depends on how much the demand is. For example, on a summer day a very large solar boiler can produce more heat than is required by a single household. When the same solar boiler system would be applied to two households, more of the produced heat will be used. Therefore, the contribution of the solar collector increases with a larger demand. These specifications are shown for each solar collector with a quality statement.
A row house is likely to have its own system. The matching demand would result in an annual energy yield of 3.7 GJ/year for 1.5 m2 collector surface. If a solar boiler would be installed on the flats, the area of the solar collectors will be limited and most probably not exceed the hot tap water demand. This results in an annual energy yield of 4.7 GJ/year for 1.5 m2. Both values are for south oriented with a tilt of 45 degrees.
An overall efficiency was found for the solar collectors that can be used as input in the model. The panels were compared for the same orientation and tilt.

Type of buildings	Annual energy yield (GJ/year) (Quality statement)	Efficiency model	Annual energy yield (GJ/year) model
Flat type 1,2,3	4.7	60%	4.62
Row houses	3.7	75%	3.70

Table 26 Annual energy yield solar boiler

It has to be noticed that the yearly energy production is the same as in the quality statement. However, in this research the efficiency of the solar collector does not depend on the ambient air temperature. This means that the energy production by the solar collector for a cold period could be overestimated and for a warm period could be underestimated.

The solar boiler can produce water of 80 degrees (Keizers, H., personal communication, December 2016). The ground source heat pump has a lower coefficient of performance for heating hot tap water than for space heating. This means it requires more electricity to heat hot tap water. Therefore, the heat from the solar boiler is primarily used for hot tap water

Applied heating strategy

Solar boiler

The hot water produced by the solar boiler, is used to fill the hot water tank and to charge the TCM modules.

- The hot water storage tank is filled when space heating is required.
- The hot water storage tank is filled when the hot water storage tank is under the required minimum.
- Otherwise the heat modules are charged.

TCM module

Whether the heat of a TCM module is released depends on a couple of factors:

- The temperature outside is lower than a certain temperature at 01:00.
- This means that it is expected that this night will be cold, which requires heat for space heating.
- The energy in the water storage tank is lower than a certain minimum.
- This provides the heat being released while there is enough energy in the water tank stored.
- There are a maximum number of modules available in the system. Which means that a module can only be used if there are more than 1 module(s) left.
- A module can only be released after July when the number of fully charged modules are higher than at the beginning of the year.

Whether the excess heat is stored in a TCM modules depends on the following factors:

- There are a maximum number of modules that could be used. If the maximum number of available TCM modules has been reached, it is not possible to store heat.
- It is not possible to store heat, while a module is releasing heat
- The energy available in the water storage tank has to be a certain minimum to make sure that there will be enough energy left for the hot water and space heating demand.
- Heat can only be stored if the solar boiler produces more than the total heating demand (hot tap water and space heating). This prevents the storage of heat, when just a heat module has released heat.

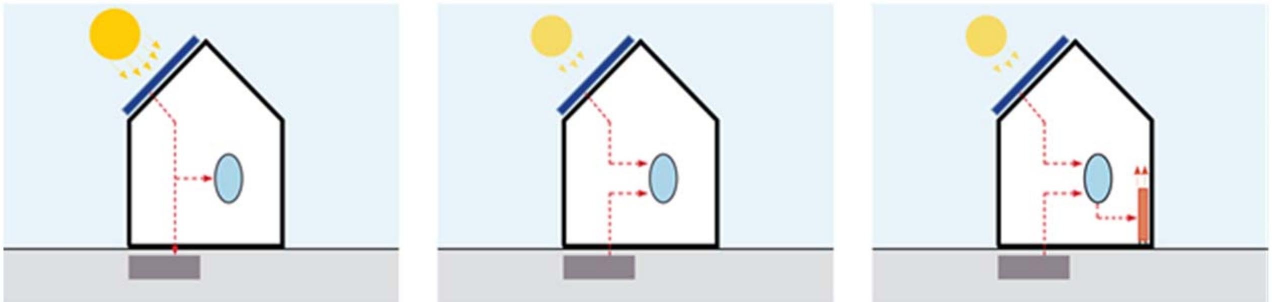

Figure 63 Concept heat storage

Hot water storage tank

The storage tank is modelled as follows:

- If the maximum of the energy that could be stored in the tank has been reached, the energy content of the tank is assumed to be the maximum energy content of the tank. This means a part of the energy is wasted.
- It is assumed that heat can be stored for the hot tap water for 24 hours. If it would be modelled more detailed, there is a loss in energy in the storage tank.
- The storage tank is modelled in such a way that there is always enough energy kept in the tank to provide hot tap water, which has a varying character during the day. For example, if the energy demand for hot tap water is 21 MJ per day, the hot water storage requires this as minimum. Nevertheless, energy from the hot water tank is used for space heating if the energy content is minimal 23 MJ. This prevents the situation that heat is used for space heating, and a couple of hours later the heat pump for hot water has to be turned on.

Heat pump

- The heat pump for hot tap water has a higher COP than for space heating. Therefore, the hot tap water is first taken from the hot water storage tank. In case there is no heat module available or no heat produced by the solar boiler, the heat pump is used to heat the hot water storage tank.
- The heat pump for the space heating is used if no heat from a TCM module is released and no heat can be taken from the hot water storage.

Design variables

This are the variable that could be changed to adjust the heating system and adjust when the heat battery starts working.

Minimum storage energy hot water (daily hot water demand)	21	MJ
Hot water storage can be used for space heating with min	48	MJ

Release module of heat battery when under	23	MJ
Energy content one module of heat storage	60	MJ
Time of operation of one module	24	hours
Energy density heat module	1000	MJ/m3
Space available in building	3	m3
Maximum to be stored energy in hot water storage (400L)	84	MJ
Release heat from module if:		
Temperature is lower than	14	degrees

Heat battery

Figure 64 - Figure 67 show the functioning of the heat battery. The battery is mainly used to provide hot tap water which requires a higher electricity demand than production of space heating. The operation of the heat battery is not fully optimized. It can reduce nearly 10% of the highest peak demand of the heat pump in winter time. When considering a week in winter (first nine days of January), an average peak demand of 17% can be achieved. There are many design variables that can be influential for the performance of the heat battery such as size of the hot water tank, number of modules, energy content of the modules, size of the solar boiler system, etc. In this research it released heat only at 01:00 am below a certain outside temperature. In future work this could be dependent of expected peaks in the grid such as charging of electric vehicles or electricity demand in the evening by households.
Figure 69 shows how the performance of the heat battery is dependent on the number of modules that are used. When just a small part of the roof is covered with a solar boiler, more modules are used during a year than it can charge it. While when nearly the full roof is covered, it stores a lot of heat in the modules and charges more modules than it used in a year. This means that the electricity demand might be higher than presented in the table. It shows that with these input variables that the use of modules is balanced when the roof is covered for 50% with solar boilers.

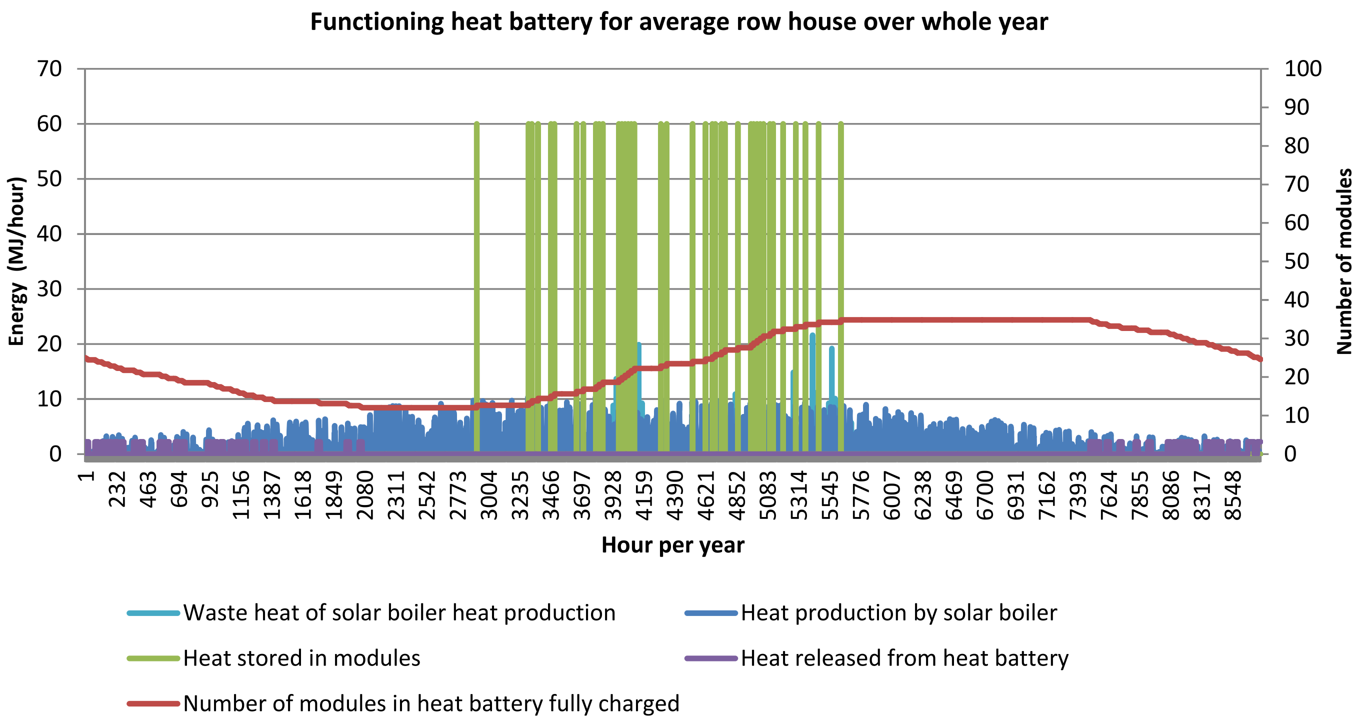

Figure 65 Functioning heat battery for average row house over whole year

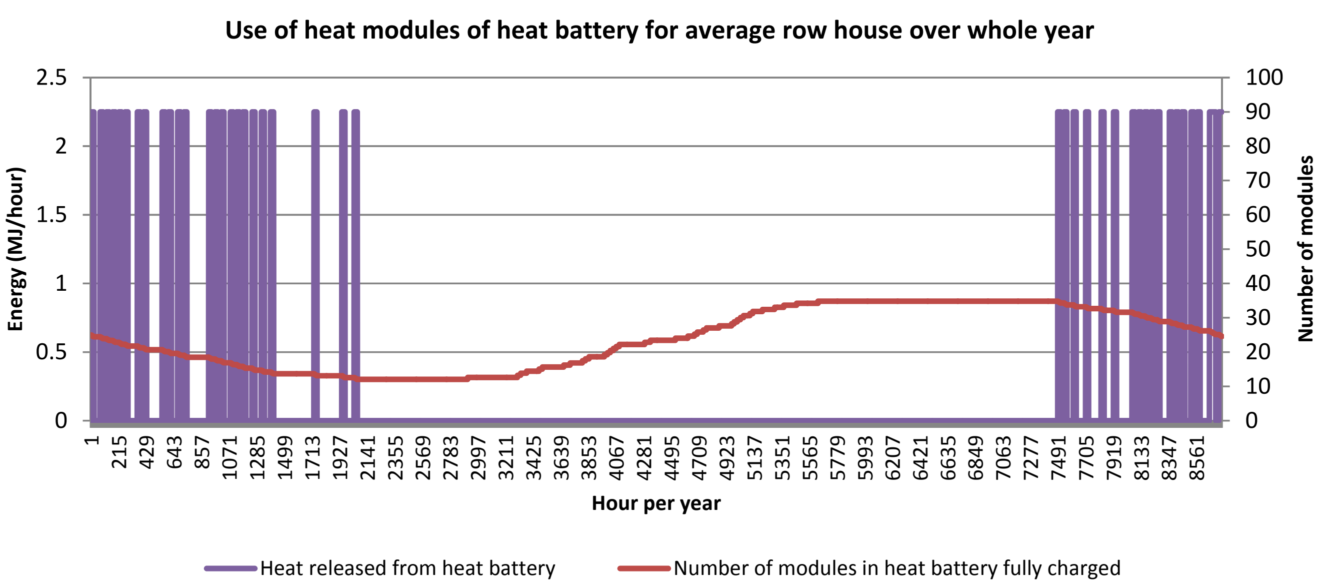

Figure 64 Use of heat modules of heat battery for average row house over whole year

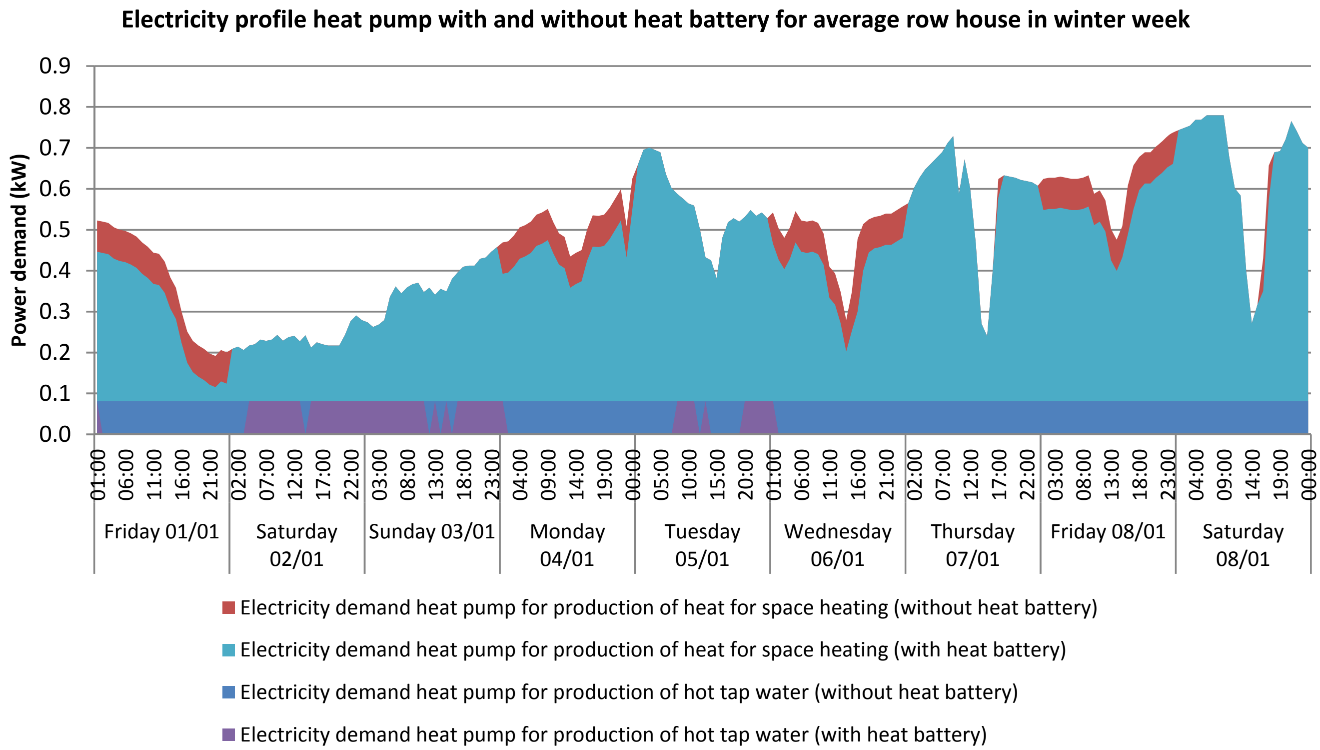

Figure 66 Electricity profile heat pump with and without heat battery for average row house in winter week

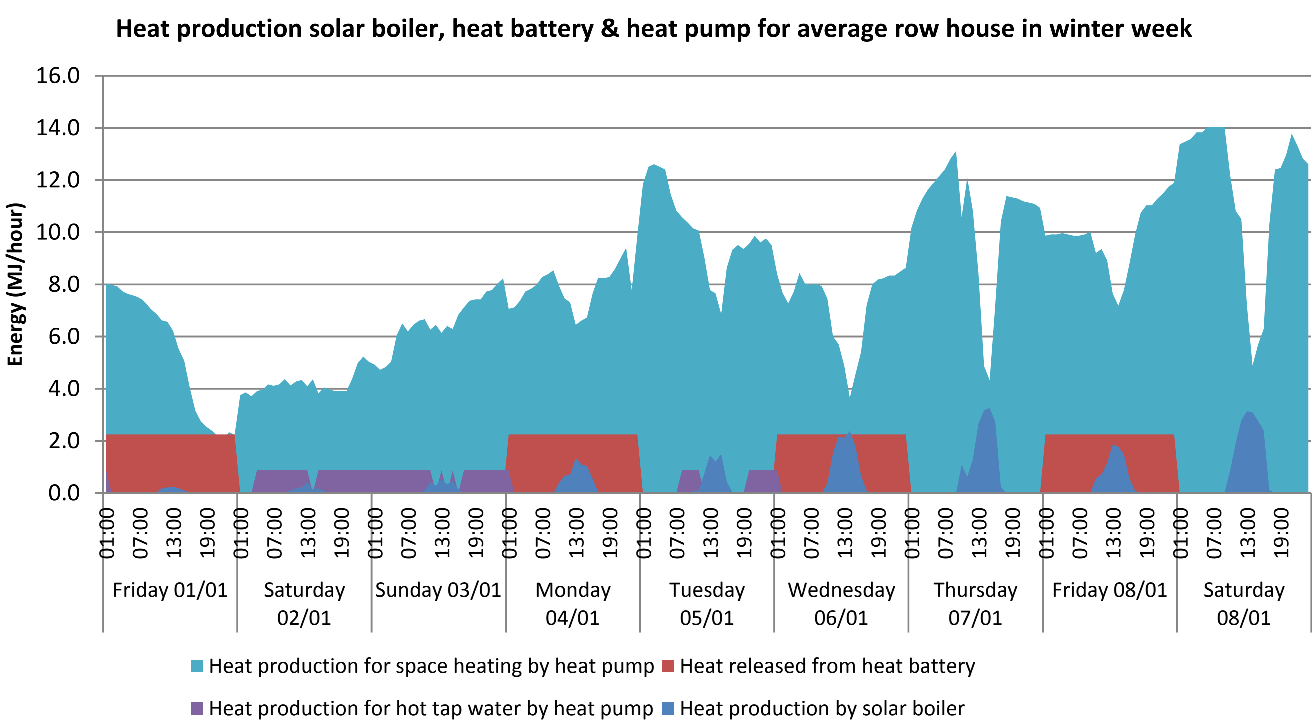

Figure 67 Heat production solar boiler, heat battery & heat pump for average row house in winter week

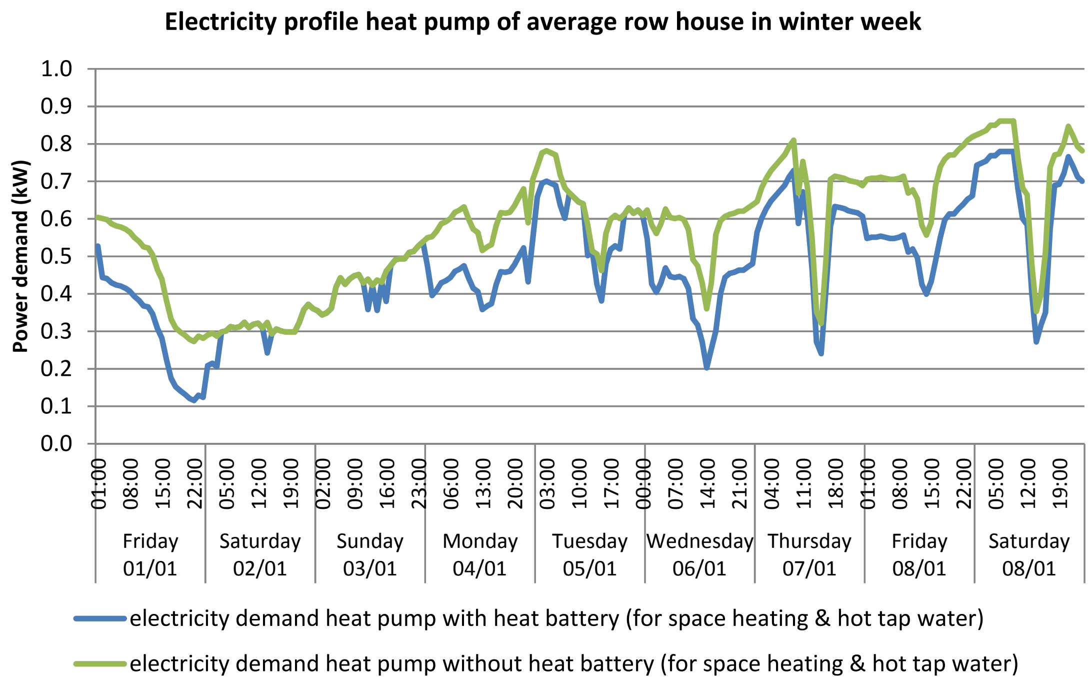

Figure 68 Electricity demand heat pump

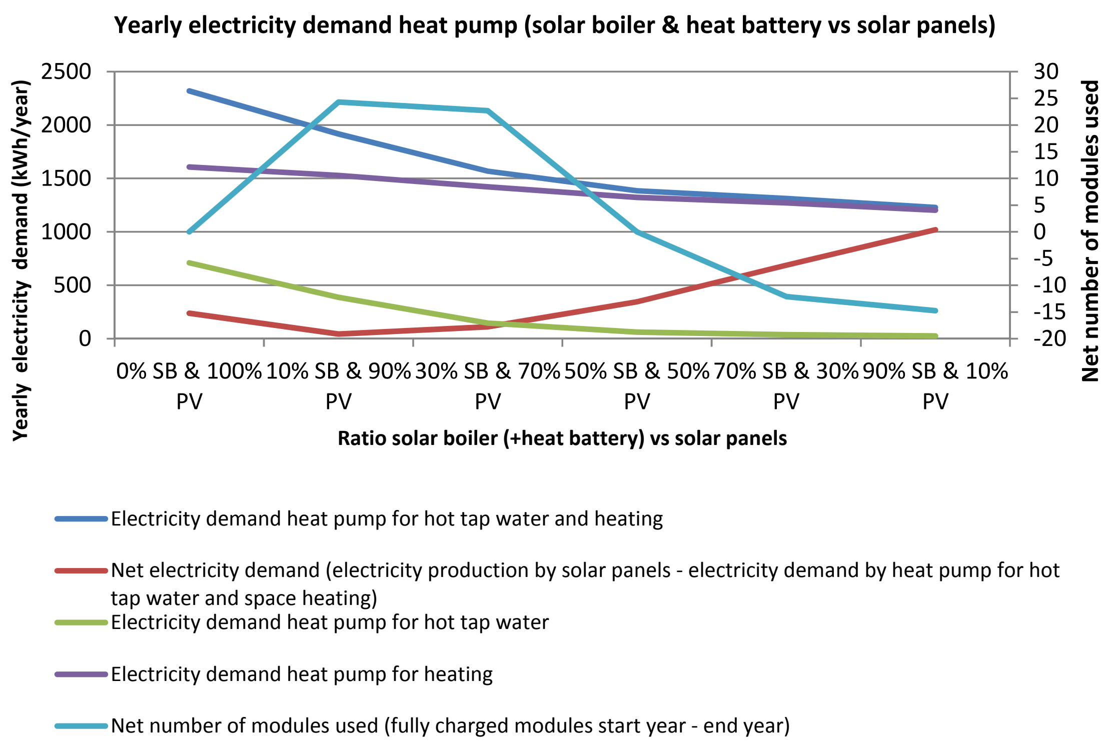

Figure 69 Yearly electricity demand heat pump (solar boiler & heat battery vs solar panels

6.5 Transport

As shown before in chapter 5, the energy used for driving a car is about 30% of the energy consumption of a household. One way to reduce this energy consumption is to replace the current cars using fossil fuel by electric vehicles (non-hybrid). The influence of the adoption of electric vehicles on the electricity grid is shown in this chapter. First, a data analysis of the driving patterns is reported. Based on these driving patterns, a charging profile of electric vehicles has been modelled, explained in chapter 6. Also the influence of different charging strategies is described.

6.5.1 Mobility patterns

The data that are used to model the driving patterns in the case study are from the (RVMK, 2015). This model is based on data from 2010 from OVIN (onderzoek Verplaatsingsgedrag in Nederland) and is one of the most extensive and strategic mobility models in the Netherlands (De Graaf, Friso, & Rijsdijk, 2015).
The dataset provides information about the number of trips; about arriving and leaving a specific area and about the means of transportation: car, bike or public transport. The number of trips is divided in three time periods on a working day (Monday-Friday): rush hour morning (07:00-09:00), rush hour afternoon (16:00-18:00) and the remaining time (10:00-15:00 & 19:00-06:00). This dataset also provides information of the purpose of the trip: shopping, education, work, commercial and remaining.

There are four challenges to use the provided dataset for the purpose of this research. First, the relevant area from the dataset is slightly larger than the case study area. This means that a part of the trips is not carried out by the inhabitants of the case study neighbourhood. Second, when using sub-results of the provided dataset, data loss occurs and the resolution is very low. Third, the dataset provides only information about a working day and three time periods (two rush hours and the rest of the day). More specific time periods and the distinction between a working day and the weekend days are preferable when modelling EV charging. The final challenge is the fact there is only information available about the total number trips, which is not linked to the number of cars.

The goal is to find out how many cars, that belong to the inhabitants of the case study, arrive in the neighbourhood, how much distance has been covered and when the cars arrive. This information can be used to estimate when electric vehicles would be charged, and for how long, and by whom.

The modal split is shown Figure 70 and Figure 71, for the area of the data set, the average for Rotterdam (Verkeer & Veroer Gemeente Rotterdam, 2016) and for the Netherlands (Berends-Ballast, 2016). The modal split includes travels by public transport, bicycle and car for the number of trips and distances.

It shows that the number of trips and distances by car a much higher in the Netherlands than in the area where the case study is located. Public transport is very small in the Netherlands while in the city of Rotterdam and case study area it is an important way of transportation. In the area of the provided dataset cycling and public transport play even a larger role compared with Rotterdam. The area has a subway station close by, which makes it more attractive to use public transport.

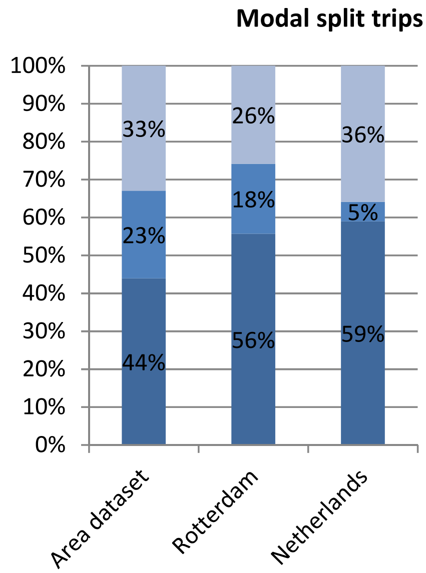

Figure 71 Modal split trips

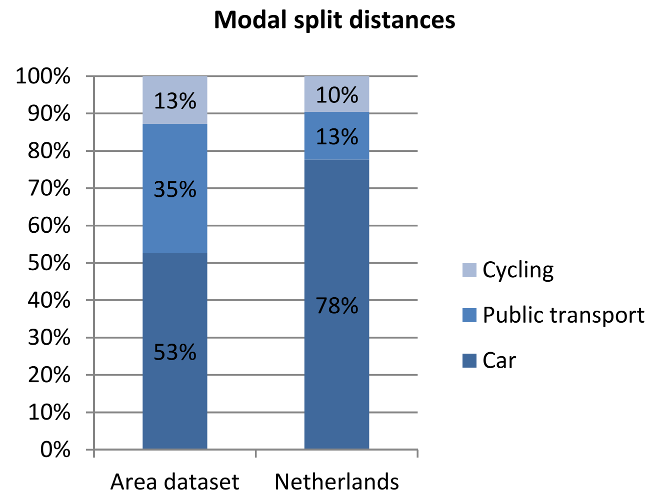

Figure 70 Modal split distances

This research focusses only on the car movements since these have influence on the charging profile of electric vehicles. The chosen scale of the area has influence on the possible measures that can be applied to reduce energy consumption of transport. When considering a larger area other ways to reduce the overall energy demand of transport could be applied such as stimulating travelling by public transport, cycling or walking or providing the possibility to work at home. On top of that, the energy demand of transport in a neighbourhood could also include vehicles that are used to maintain the public space such as cleaning the street or picking up garbage. This research considers only the movements of inhabitants.

Area and case study

The area that is used to collect transport data from is slightly bigger than the case study neighbourhood, shown in Table 27. In the case study only households are considered, while the area of the dataset includes other functions such as a church, fitness school, kindergarten and a school.

	Area of dataset	Case study neighbourhood
Number of pupils	486	0
Number of employees	70	0
Number of households	382	324
Total number inhabitants	653	569

Table 27 Area and case study

The dataset of the area consist of 1200 car trips (leave and arrive) on a working day. Not all trips that are made can be counted for the case study neighbourhood. The first step is to zoom in to the purpose of the trips.

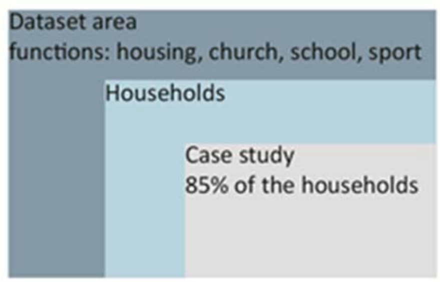

Figure 72 Part of dataset accounted for case study

The Figure 76 shows the percentage of the trips per purpose and the average distance per purpose of the trip.
The following assumptions are made to match the trips to the function in the area.
There are no shopping facilities in this area, which means that all shopping trips are carried out by the households in the neighbourhood. This means that no trips are made by others to come to the neighbourhood for shopping. An explanation will be given later.
The dataset from the (RVMK, 2015) shows a relative high amount of trips with as goal education. This can be explained by the fact that there is a school in the area. In contrary, it can be concluded from (Harikumaran, 2012) that is based on the average Dutch mobility data, that the number of trips and distance with the purpose education is very low compared to the other purposes. Therefore, the trips with the purpose education are not carried out by the households in this research.

It is not clear whether the trips with purpose work are carried out by the inhabitants driving to the outside of the area to work or people living outside the area and driving to work in the area. It is assumed that 90% of the trips that arrive in the morning rush hour and leave in the afternoon rush hour are made by people that are working in the area. In other time periods, 95% of the trips with purpose work are carried out by the inhabitants.
Commercial trips are a very small percentage of the total. The same assumptions are made as for the trips with purpose work.

All remaining trips could include leisure time, sports, visiting friends or family and happen the whole week. It is assumed that 95% of these trips belong to the households. The remaining 5% could be trips of people from outside the neighbourhood such as visitors of one of the inhabitants, the church or fitness school.
These assumptions result in the following division of trips. This is compared to Dutch averages (CBS, 2016c).

It shows that the number of trips shopping and work is significant lower than the average. The remaining trips are higher. One explanation could be that a shopping area is close by, reachable by bike or foot. Even when the number of trips of work are fully carried out by the households, this results in 20%. One explanation could be that there is a subway station is close by. Education is left out in this study, while it accounts for only 2% of all trips. The trips with purpose commercial are added to the trips with purpose work.
The trips with purpose working and shopping are lower than the Dutch average. The trips with purpose remaining are higher in this area.

The driving pattern is estimated for the whole area, which includes 382 households. In the case study are only 324 households. Therefore, only 85% of the number of trips that are counted for by the households in the case study area.

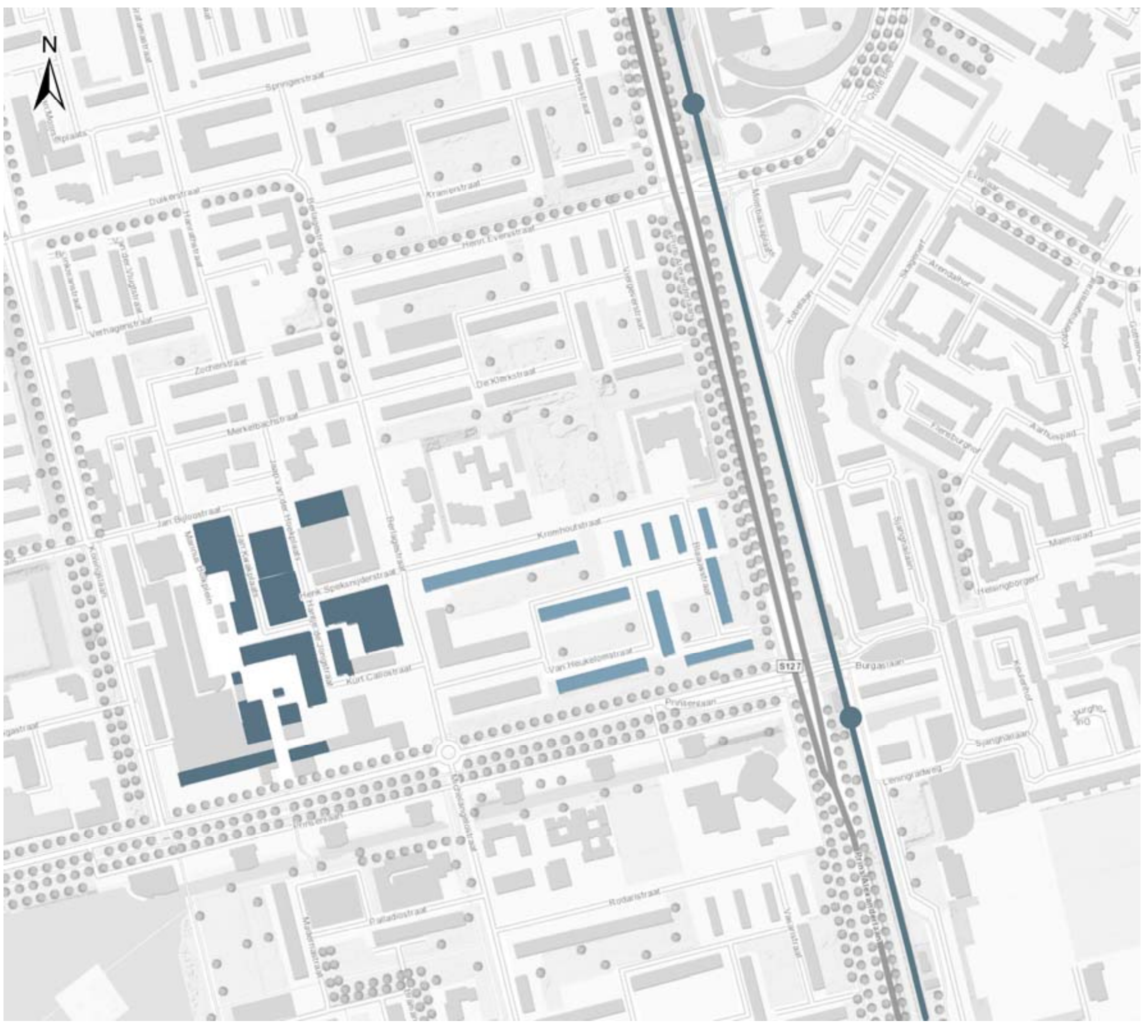

Figure 73 Shopping area (left) and subway station (right) close by

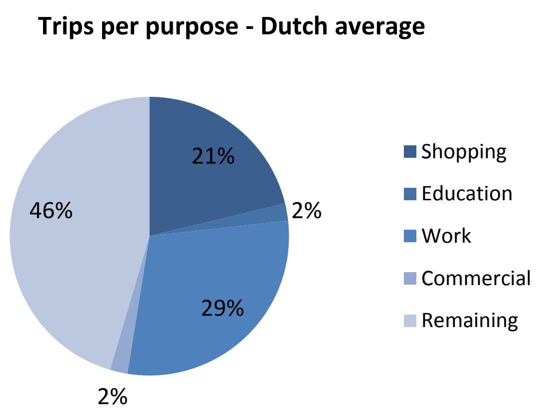

Figure 74 Trips per purpose Dutch average (CBS, 2016c)

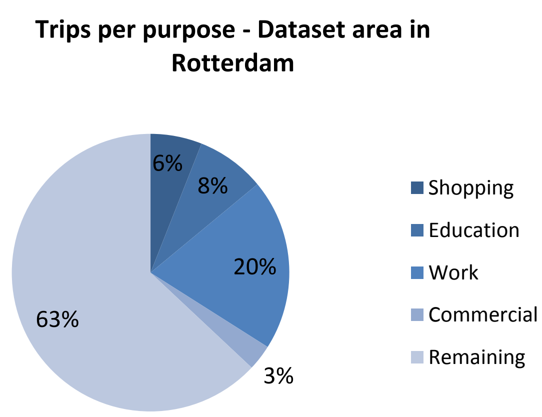

Figure 75 Trips per purpose dataset area in Rotterdam

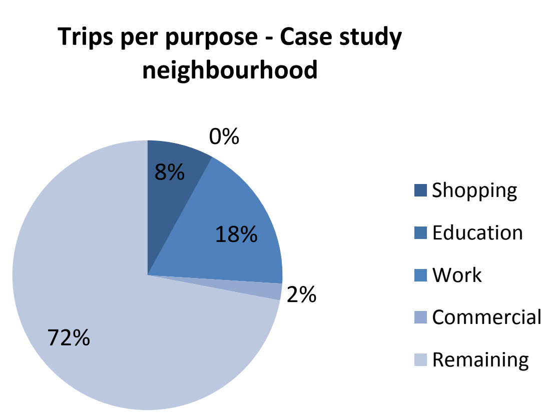

Figure 76 Trips per purpose case study neighbourhood

Data loss

In what time period the cars will be charged is important for modelling a charging profile. The dataset does not provide information about which specific car arrives and leave the area at what time. Therefore, only the arrival data are used and an assumption will be made how long the car will be parked.
Data loss occurs in sub-results in the provided dataset. For example, the sum of leaving and arriving trips is not the same as the total number of trips. It is not clear why this happens. An underestimation of the number of trips, could lead to a lower electricity demand. Therefore, all arrival and leave data are multiplied by a factor of 1.05 to compensate the data loss. This factor is chosen because it corresponds to the delta in size of the previously mentioned data sets.
Data loss occurs in some categories more than others. An additional compensation has to be made. Trips are added in sub categories where data losses occurs; for instance arrivals in afternoon rush hour with purpose shopping. These adjustments that are made are always checked with the (sub) totals. In case of the example, checked with arrivals in afternoon rush hour for all functions and checked with the arrivals during the whole day for the purpose shopping.
How long the cars need to be charged depends on the distance that has been covered. It is possible to link the destination and purpose of the trip with the arriving time period. This creates two challenges. First, using this data would result in even more data loss and lower resolution. This could lead to unrealistic outcomes because for some time frames per destinations there is only one trip. The question is whether this is a representative distance of this time frame. Second, it would be hard to estimate whether a trip is carried out by an inhabitant or an employee working in the area. To overcome these two problems, an average distance per purpose of each trip has been defined.
The transport model is developed for the region Rotterdam. The destinations within the region are specified with a name of a city, which made it possible to estimate the distance. However, destinations outside the region Rotterdam were very vague such as: South of the Netherlands. A map (RVMK, 2015) was used, where all trips were highlighted, to give a better estimation of the distance. It was found that most of the cars have their destination within a range 35 km, just outside the Rotterdam region, and do not travel to the other side of the country frequently.

The following distances are used for the destinations:
Nederland (Noord-West, Noord-Oost, Zuid-Oost, Zuid-West) = 32 km each
Zeeland west = 45 km
P + R (location Kralingse Zoom which is the closest) = 4 km.
All other distances were found with help of google maps.

The average distance that was covered per trip based on these estimations is 13.2 km/trip. This results in the same average distance (13.17 km/trip) as provided by the model of (RVMK, 2015), calculated with a separate sheet.
The results of the average distance per purpose is shown in Figure 76.
Based on figure 3.10 in (Harikumaran, 2012) the following average distances per purpose of trip are found for Dutch averages and compared with the results of the data analysis. It shows that the average distance per trip in Rotterdam is smaller than the Dutch average.

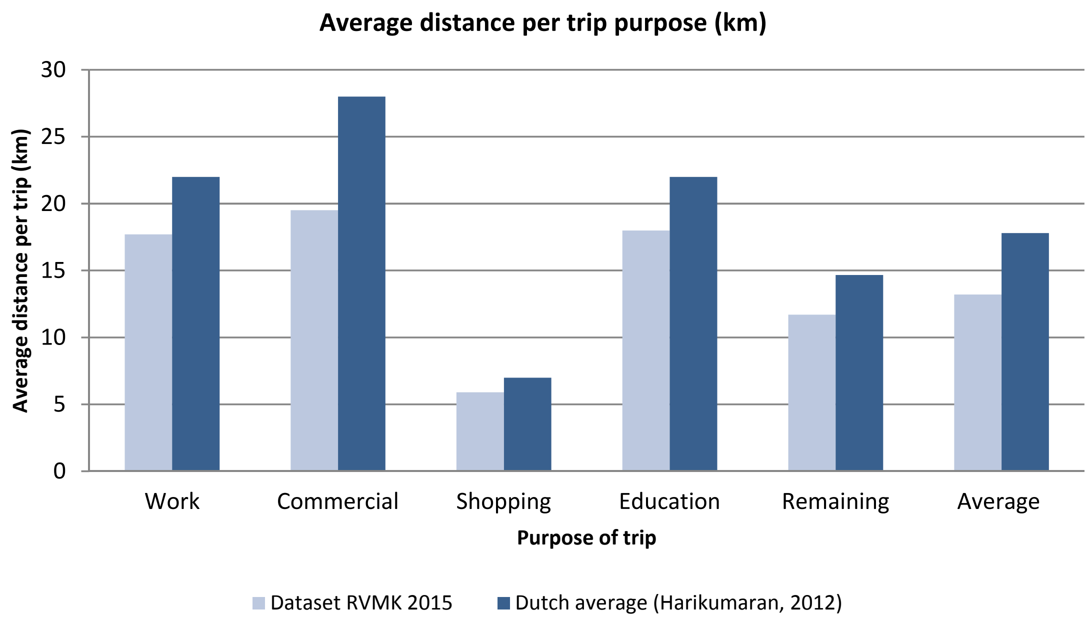

Figure 77 Average distance per trip purpose (km)

Timetables

The data set provides information about three time periods on a working day: rush hour morning (07:00-09:00), rush hour afternoon (16:00-18:00) and the remaining time (10:00-15:00 & 19:00-06:00). A more specific time estimation of the number of trips can be made in combination with the busyness on the roads (Verkeer & Veroer Gemeente Rotterdam, 2016). The ratio is shown in the Table 28. Now, the number of trips can be divided over five time periods on a regular working day.

	Daytime	Evening	Night
Time	07:00-19:00	19:00-23:00	23:00-07:00
Percentage of total number of trips	77%	13%	10%

Table 28 Busyness on road during a working day

The dataset does not provide any information about the weekends. A similar ratio was found to estimate the difference of busyness on the road for a working day and a weekend day (Verkeer & Veroer Gemeente Rotterdam, 2016).

Busyness per day	Working day	Average week day	Weekend day
Percentage	100%	92%	72%
Number of trips	1200	1104	864

Table 29 Busyness on road during a working day and weekend day

This shows that less trips are made in the weekend. In (Harikumaran, 2012) a clear difference is found between Saturday and Sunday. To estimate this difference, measurements of busyness on the road close by the neighbourhood; Prinsalexanderlaan 1, average of two different weeks in March (Verkeer & Veroer Gemeente Rotterdam, 2016) have been used. This results in a significant higher occupancy on Saturday than on Sunday.

These same measurements of busyness on the road are used to estimate when cars arrive in the neighbourhood in the weekend. This shows the difference of busyness on the road compared to a working day in Figure 78. The night has a slightly higher occupancy due to the night life of the previous night. This means that a Sunday early morning has an increase due to the public going out on Saturday night.

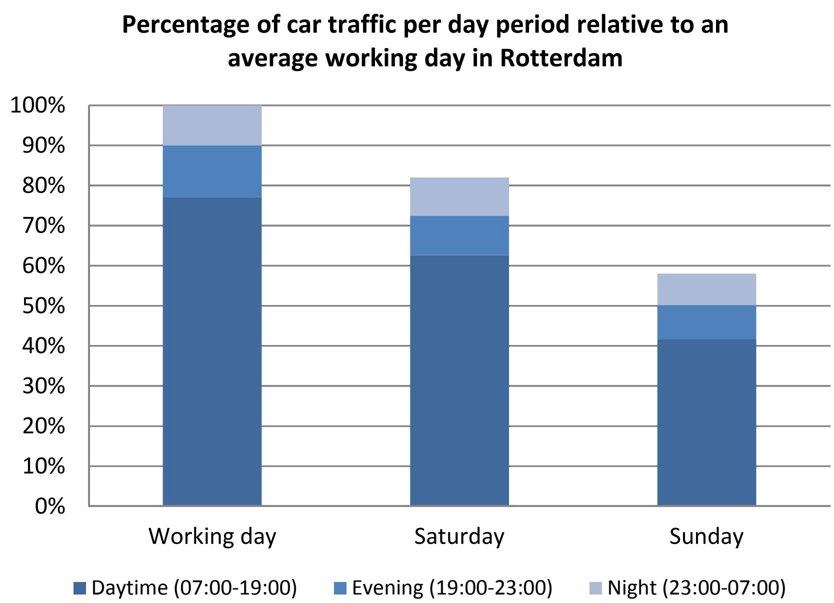

Figure 78 Percentage of car traffic per day period relative to an average working day in Rotterdam

It is assumed that trips with purpose shopping and remaining (leisure) also happen in the weekend. Trips with working and commercial purposes happen less compared to a working day.

More than half of the people working have irregular working schemes. This means that these people have to work occasionally or regularly in the evening, at night, on Saturday or Sunday (CBS, 2016a).

Compensation factors		**Percentage of data per purpose trip per function**					
Factor	Factor	Shopping	Work		Commercial		Remaining
Day of the week	Weekend compensation	All day	(arrive morning rush hour, leave afternoon rush hour)	Rest of the day	(arrive morning rush hour, leave afternoon rush hour)	Rest of the day	All day
Working day	100%	100%	10%	95%	10%	95%	95%
Saturday	84.6%	100%	2%	14%	2%	14%	95%
Sunday	69.8%	100%	2%	14%	2%	14%	95%

Table 30 Percentage of trips accounted for households.

This shows that the number of people working in the weekends cannot be neglected. It lacks specific information to extract the absolute numbers. The weekly profile of the number of trips per purpose found in (Harikumaran, 2012), shows that the number of trips with the purpose work or commute are significant lower in the weekend. In (Berends-Ballast, 2016) it was stated that commute trips are less than 20% in the weekends compared to a working day. For this research it is assumed that the working trips in the weekend are 15% of the number of trips during the working days (this results in 14% and 2% because it is multiplied by 95% and 10%).

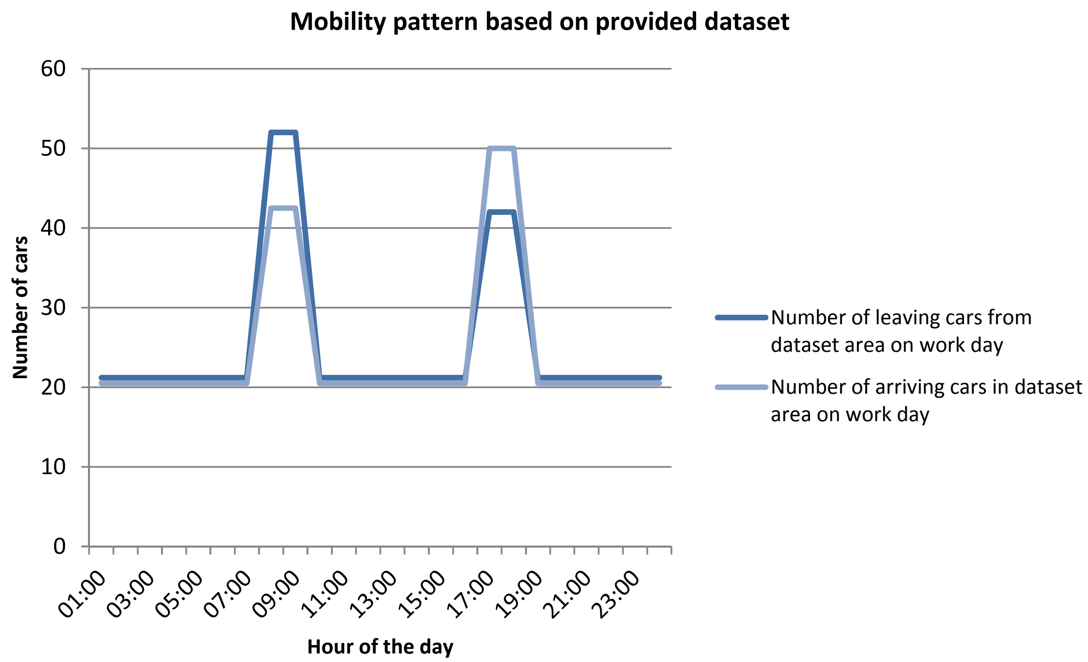

Figure 79 Mobility pattern based on provided dataset

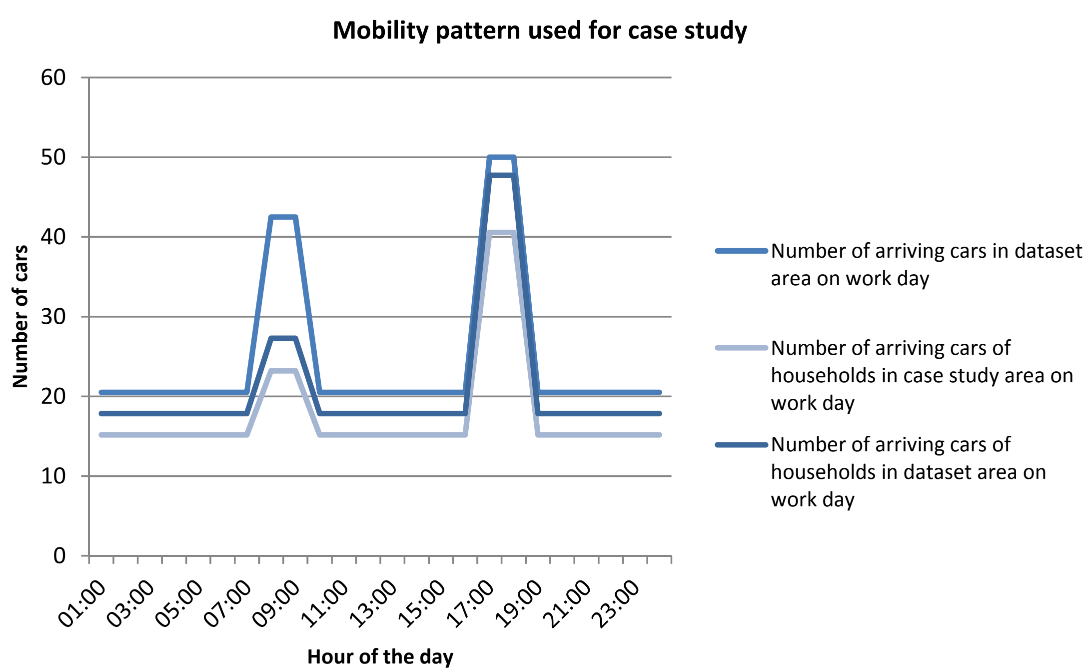

Figure 80 Mobility pattern used for case study

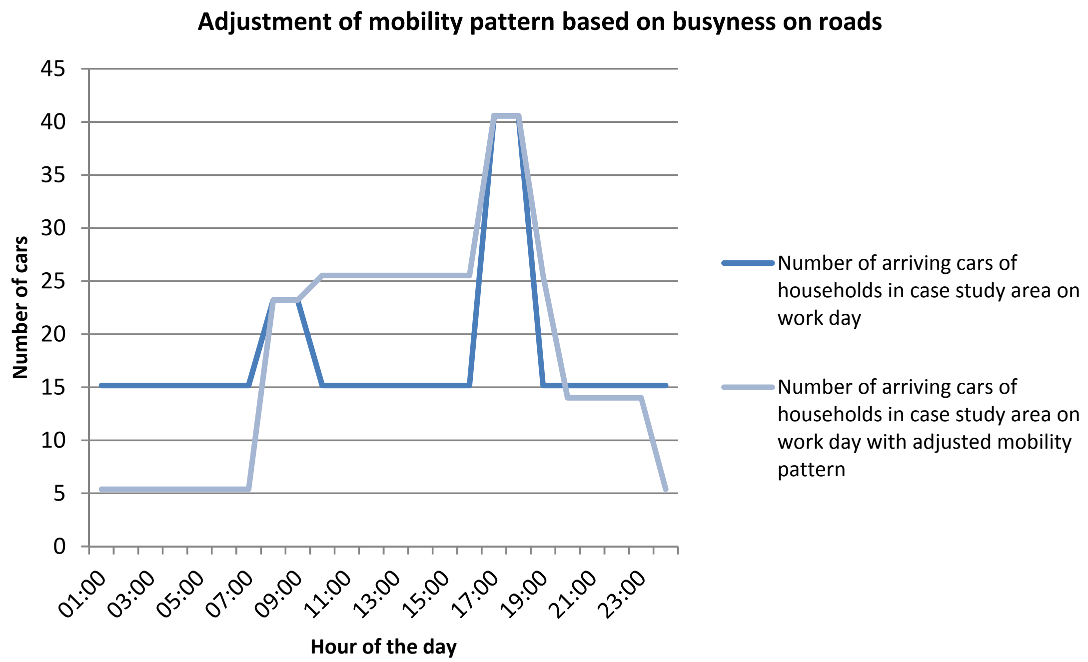

Figure 81 Adjustment of mobility pattern based on busyness on roads

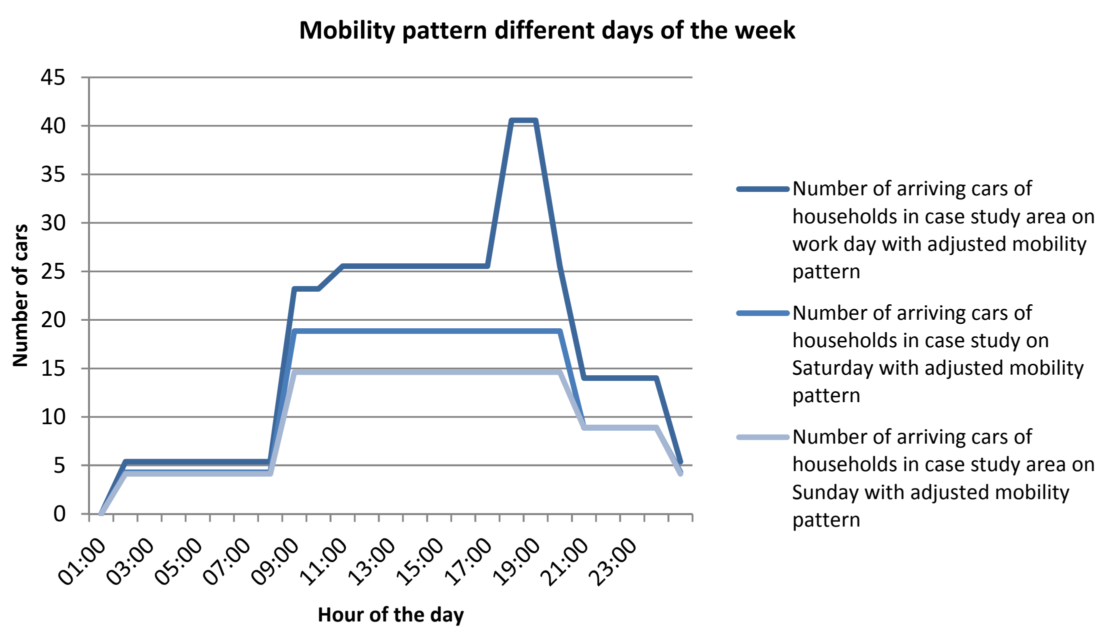

Figure 82 Mobility pattern different days of the week

Ownership car

The number of cars owned by the inhabitants in the neighbourhood has influence on the number of trips that are made per car. Data about car ownership was provided on zipping code 5 area, which is a larger area than the case study (Overmorgen, 2016). The case study neighbourhood holds two zipping code areas, shown in the table below. The number of cars per household is very different. A weighted average is taken for all type of buildings in the case study. Company cars are not registered at the home address. Therefore, the number of cars is increased with 10% (Van Rijthoven, R., personal communication, December 2016). This results in 0.97 cars per household, which is similar to the Dutch statistics of 1.04 car/household (Harikumaran, 2012).

		Total area			Case study		
PC5 area	Factor not registered cars	Number of households	Cars	Cars/hh	Number of households	Cars	Cars/hh
3067A	1.1	1772	622	0.35	160	56	
3067P	1.1	371	581	1.57	164	257	
Total		2143	1202	1.13	324	313	0.97

Table 31 Ownership cars in case study

However, a significant lower of 0.6 cars per household was found on CBS (even with an additional 10% of company cars) (CBS, 2016b). These numbers are shown on a larger area (4 zip code numbers) than the data provided by (Overmorgen, 2016) which is on zipping code 5 area. For this research the data from the more detailed area are chosen, which is similar to the Dutch average.

The lower car ownership was tested in the model to check what the influence was. This resulted in a significant higher number of trips per day; 4 trips per day and an average distance driven per day of 50 km per car. This seems unrealistic compares to the Dutch mobility data. The RVMK model is based on the number of households. It is uncertain whether the RVMK model takes into account the number of cars per household.

Based on the number of cars in the neighbourhood, the number of trips per car and the data about trips per purpose, the number of cars that drive to work can be derived.
The number of cars that drive to work is the total number of arriving trips with purpose work or commercial. The remaining number of cars is assumed not to drive to work. This results in a division of 30% of the cars drive to work and 70% of the cars are used not to drive to work.

The average number of trips per car is assumed to be the same for both type of cars. It has to be clearly stated that this is an assumption based on the data that is available. If more detailed data would be available it would be worth to find out what the average number of trips and distance is between cars that drive to work and cars that do not drive to work.
A car used to drive to work has two trips for purpose work or commercial, the remaining number of trips for shopping and remaining. For cars that are not used to drive to work, all trips have the purpose shopping or remaining. This way the covered distance per car has been calculated. The result for a working day is shown in Table 32.

	Number of cars	Average number of trips per day	Number of trips working	Number of trips shopping and remaining	Average distance per day (km)
Case study	315	2.46			30.5
Working day					
Working cars	99	2.76	2	0.76	44
Non-working cars	216	2.76	0	2.76	31
Saturday					
Working cars	13	2	2	0	36
Non-working cars	284	2	0	2	22
Not used cars	19	0	0	0	0
Sunday					
Working cars	10	2	2	0	36
Non-working cars	233	2	0	2	22
Not used cars	71	0	0	0	0

Table 32 Trips division between the cars

A lower number of trips take place in the weekend. In case this results in a number of trips lower than two trips per car per day, it is assumed that a part of the cars drive two trips per day while the other part is not used that day.

Comparison data with average Dutch statistics

The acquired data are compared with average Dutch mobility data. It shows that the number of trips in this neighbourhood is higher, while the distance driven per vehicle per day is lower. The number of cars per household is comparable.

Mobility	Derived from MON Survey (Harikumaran, 2012)	Case study (households)
Persons per vehicle	2.15	1.8
Average no of trips per vehicle per day	2.09	2.44
Average distance per vehicle per day	35.67 km	30.3 km
Vehicles per household	1.04	0.97

Table 33 Outcome mobility Dutch average and model

The number of persons per vehicle is lower for the case study than the Dutch average. A reason could be that the size of the households in the case study neighbourhood is smaller than the Dutch average. Comparing the household size (1.76 persons per household in the case study) with car ownership, results in 1.89 persons per car (Van Beuningen, Molnár-in ’t Veld, & Bouhuijs, 2012). This could give the explanation why there is a higher number of cars per person but a lower number of cars per household compared to the Dutch averages.
(RVMK, 2016) mobility model is based on MON data. This could be explained by the fact that that the number of trips that was measured by the city on the streets and the data from MON didn’t correspond (Van Rijthoven, R., personal communication, December 2016). A

given reason was that the MON data are partly based on questionnaires and respondents might forget to fill in there short trips (just around the corner). Therefore, more short trips were added to the RVMK model, which could explain the difference in number of trips.

6.5.2 Charging strategy

Charging electric vehicles requires electricity. This can cause high peak demands when many cars are being charged at the same time. The amount of power requested depends on the charging strategy that is applied. This is highly dependent on where, how long and when car users charge their car.

For this study, it is assumed that the current driving pattern does not change when cars on fossil fuels are replaced by electric vehicles. This means that no change in behaviour is taken into account such as the effect of an almost empty battery or costs of charging. It is hard to estimate where the inhabitants of the case study will charge their car in future. This depends on many factors, such as price, size of car and battery, distances driven, subsidies, pro-active attitude of companies.

Therefore, it is chosen to compare the effect of charging for three different scenarios.
1: Scenario H: at home charging
2: Scenario W: at work charging
3: Scenario H & W: 50% at work, 50% at home charging

The data shows that not all cars in the neighbourhood drive to work. These scenarios apply only for the cars that are used to drive to work. The rest of the cars are assumed to charge their car at home; charging on other places such as fast charging along the high way is not considered. The impact of this charging strategy to the total energy use is expected to be very low, given the low number of long distance trips made by the inhabitants, as defined in the beginning of this chapter.

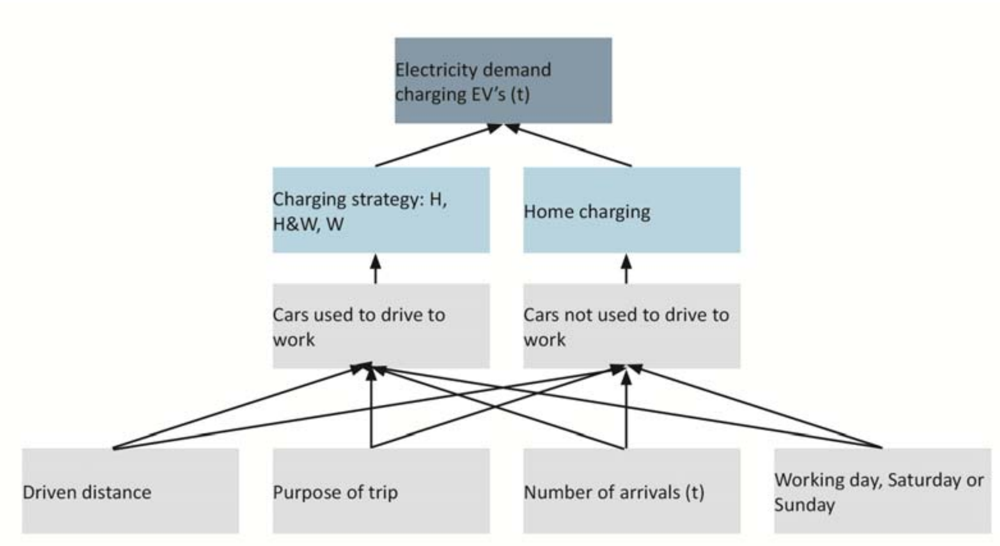

Figure 83 Electricity demand charging of EV's

It is assumed that the cars that can charge at work (30% of the cars), are sufficiently charged to use the car during the weekend. The average distance that is covered in the weekend is lower than during the week. When adding the average distance of one working day, one

Saturday and one Sunday, it results in less than 100 km. EVs that are currently on the market have already this driving range (Battery_University, 2016).

It is assumed that charging happens uncontrolled. This means that when people arrive at home, they charge their vehicle with the maximum available power. This could lead to an enormous peak in the evening hours. In future work, the effect of smart charging could be explored.

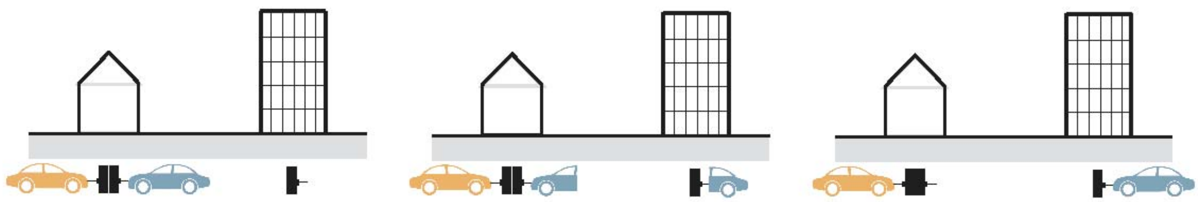

Figure 84 Charging strategies H, H&W and W

A typical home charger in Europe has the following characteristics: 230 V, 16 A, 3.7 kW. In (Halvgaard et al., 2012) the car is charged with 10 A to leave some power for other appliances in the house. In this research the charging velocity is at the full power 3.7 kW per hour (e-Station, 2016).
The well to wheel energy that is needed has been calculated in order to compare the cars on fossil fuel and electric vehicles. The primary energy is used to estimate the total energy that is required to use a car.

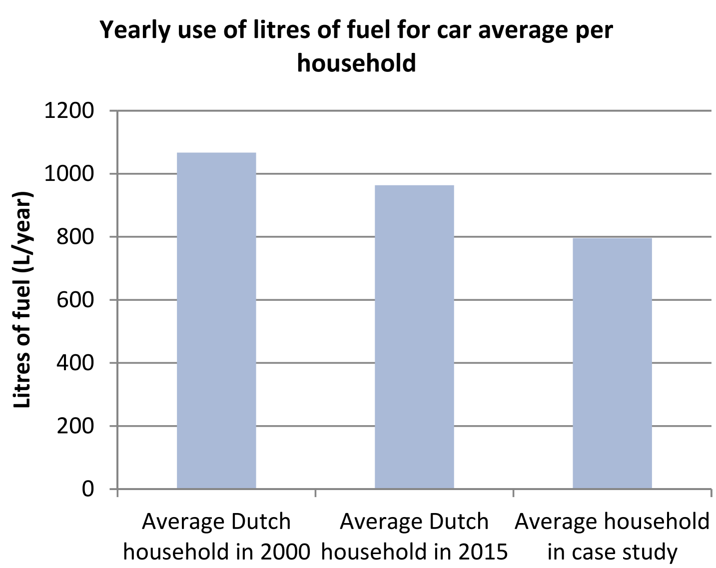

Figure 85 Yearly use of litres of fuel for car average per household

The graph in (Verbeek & Kampman, 2012) shows that the primary energy use of a petrol car is around 2.7 MJ/km, around 2.4 MJ/km for a diesel car and 2.6 MJ/km for a LPG car. This results in an average fuel use of 13.5 km/litre, when taking the weighted average energy content of the mixture of fuels of 34.5MJ/litre (Gerdes et al., 2016).

The primary energy consumption of an electric car is lower, namely 1.7 MJ/km when charged with the current electricity mix in the Netherlands (Verbeek & Kampman, 2012). Multiplying the required electricity per km of 0.22 kWh/km (Harikumaran, 2012).with the current energy mix of is 8.064 MJ/kWh (Gerdes et al., 2016), gives a similar result (1.77 MJ/km). If the electric car would be charged with renewables only, the primary energy would be significant lower, namely 3.6 MJ/kWh.
The average driven distance per car that drives to work and the car that is not used to drive to work has been determined, see Table 34 and Table 35. This results in a required energy and time that is needed to recharge the car. When charging a car with a home charger, the first 80% is charged with a constant current. In the last 20% the power goes does non-linearly down to zero. Modelling this would require a smaller time step than one hour. In this model, the car is not charged at full power in the last time step but spread out over one hour. For example, if a car arrives at 08:00, which means in the time period of 07:01 till 08:00, and needs 2.4 hours to recharge, the car will be charge in the time step 08:00 for one hour, in time step 09:00 for one hour and 40% in time step 10:00.

The energy use from grid to wheel for an electric car per driven kilometre is 0.22 kWh/km (Harikumaran, 2012). This includes the charger efficiency of 92%, battery efficiency of 85% and vehicle efficiency of 86.7% and energy required at wheel of 0.15 kWh/km.

Summary Charging scheme	Cars driving to work			
Households	Distance driven on arrival (km)	Energy required to charge (kWh)	Number of hours charging	Number of cars
Working day	44.2	9.7	2.6	99
Saturday	35.8	7.9	2.1	13
Sunday	35.7	7.9	2.1	10

Table 34 Charging of cars that are used to drive to work with

Summary Charging scheme	Cars that are not used to drive to work			
Households	Distance driven on arrival (km)	Energy required to charge (kWh)	Number of hours charging	Number of cars
Working day	30.6	6.7	1.8	216
Saturday	22.2	4.9	1.3	284
Sunday	22.2	4.9	1.3	234

Table 35 Charging of cars that are not used to drive to work with

It is assumed that a car that makes several trips per day, will be charged only once a day. This results is a lower number of arriving trips per time slot and an increasing distance that has to be charged. This is equally distributed according to the arrival data since there is no information when a car arrives and leaves. When this information would be available, it would be possible to estimate when the cars arrive and when the cars are being charged. This could result in a different ratio among the different time periods on a day.
As described earlier, in case the average number of trips is less than two per day per car, a part of the cars will drive back and forward and the other cars are not used on that day. In this case, only the cars that are used are charged.
It might happen that some decides to charge the car the day after because it is still nearly full. If more inhabitants decide to do so, this could lead to an enormous peak. However, this is not the scope of this research.

Findings transport

The dataset provided by the RVMK results in comparison with the Dutch mobility statistics in a higher number of trips but a lower driving distance per car. The number of trips in the area were not all carried out by the households. By analysing the purpose of the trips, it was possible to give an indication what trips belong to the households. Based on busyness factors provided by (Verkeer & Veroer Gemeente Rotterdam, 2016) it was possible to make different timetables according to the time period of the day and the day of the week.
Based on these driving patterns, a general charging strategy has been developed. Average distances and average number of trips per car are used. In reality these might be more distributed resulting in a different charging behaviour. For example, the average distances per trip due to data loss and low resolution. When a larger area is considered, the driven distances can be linked to the time frame (rush hour morning or afternoon or remaining hours). It would still be hard to estimate what part of the trips is carried out by the households. The current data set provides information about the number of arrivals in the neighbourhood. However, it is not sure if four cars arrive one time a day each or one car arrives four times a day while the other three are not used. This research does not model single car movements including their state of charge of the battery and their distance covered. More accurate data, which includes unique car ids in combination with driven distance, number of trips, purpose of the trips, arrival and leaving data, would be needed to model single car movements. This way, separate charging profiles could be simulated based on unique driving patterns.

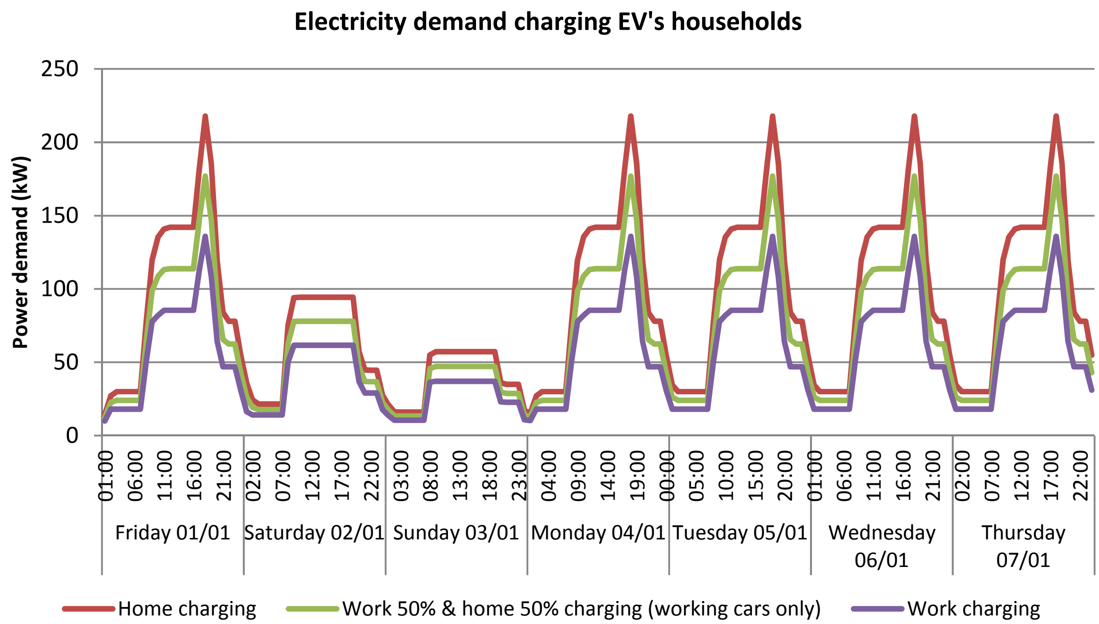

Figure 86 Electricity demand charging EV's households

The Figure 86 shows the impact of the different charging strategies (3.7 kW). The peak is the highest when all inhabitants charge their car at home. In case all cars that are used to drive to work, are charged at work, this reduces the peak demand. The ratio between the different strategies is the same because no difference could been made in arrivals between the type of cars (used for working or not- working purpose).

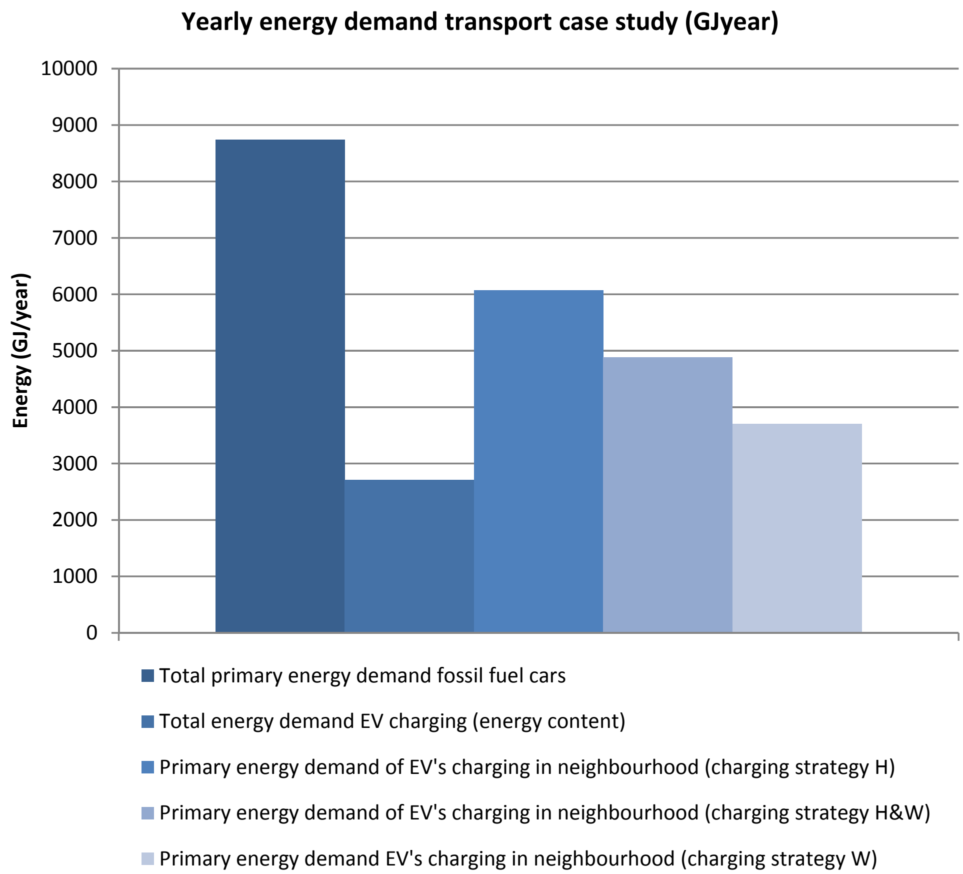

Figure 87 Yearly energy demand transport neighbourhood (GJ)

Figure 87 shows the energy demand of transport by cars in the neighbourhood. The first column shows the primary energy demand of cars using fossil fuels. When these are replaced by EV's results in an energy content, shown in the second column. The third column shows the primary energy demand of EV's if they would be charged with the current electricity mix, all charged in the neighbourhood. The next column shows the primary energy demand when half of the cars that are used to drive to work, are charged at work. The last column shows the primary energy demand in case all cars that are used to drive to work are charged at work.

6.6 Scenarios

Different scenarios will be presented in order to compare the impact of the improvements. This will be shown on a time step of an hour and a year.
The scenarios contain different sets of improvements. The scenarios are:

A combination of these difference situation can be made in the form of scenarios:

Scenarios	Situation technologies
Scenario 0	LP (C)
Scenario 1	LP (C) + PV
Scenario 2	LP (C) + PV + EV (H)
Scenario 3	LP (I) + PV + EV (W)
Scenario 4	LP (C) + PV + EV (H) + HP (C)
Scenario 5	LP (I) + PV + EV (W) + HP (I)
Scenario 6	LP (C) + PV + HP (C)
Scenario 7	LP (I) + PV + HP (I)

Table 36 Overview of scenarios

The scenarios are composed of the following situations:
(C) = current situation
(I) = improved situation
HP (C) = heat pump provides heating, cooling and hot tap water in the buildings with the current energy performance
HP (I) = heat pump provides heating, cooling and hot tap water in the buildings with the improved energy performance
LP (C) = load profile; electricity demand neighbourhood in current situation
LP (I) = load profile; electricity demand neighbourhood with LED lights
PV = electricity production by solar panels
EV (H) = home charging EV’s
EV (H&W) = home and work charging EV’s (only cars used to drive to work)
EV (W) = work charging EV’s (only cars used to drive to work)

6.7 Summary

The model is developed together with a case study neighbourhood. This existing neighbourhood is located in the city of Rotterdam. It has four different type of buildings which allow to make a comparison between their energy profiles.
The scale of the neighbourhood allows to simplify the sub models. Transport and street lights were modelled on neighbourhood level while improvements in the energy performance of the buildings were modelled per building type. Individual energy profiles are not considered on these scales. In general, the availability of local data is limited. Therefore, a combination of local and average data was used.
Nevertheless, a difference in energy profiles can be noticed between the case study neighbourhood and Dutch averages.

7 Validation model

7.1 Electricity

Sun simulator

The sun simulator SunCalc (Hoffmann, 2016) has been used to validate the sun simulator built in this model. Different time periods on different locations showed a similar outcome.

Solar panels

One way to check whether the direct and diffuse radiation formulas are correctly working is by entering the tilt of the solar panels as zero degrees. This means that diffuse and direct radiation is supposed to be the same as global radiation. This proved to be correct.
(Chandra Mouli et al., 2016) is used to validate the energy production by solar panels. The model uses data from the KNMI 2010 and the NEN dataset, while the validation paper used KNMI 2011-2013.
The annual energy yield of the model differs 4% and -2% compared to the validation paper. The difference in annual energy yield can be explained by the fact that the global radiation per year is different. Also in the validation paper, weather data of three different years were. These differ between 1 -3 % from each other.

	Model	Model	Validation paper
Weather data	KNMI, CESAR database	NEN reference year	KNMI, CESAR database
Location	Cabauw	--	Cabauw
Years	2010	several	2011-2013
Modules	30	30	30
Panels	Sun power module E20 – 327	Sun power module E20 – 327	Sun power module E20 – 327
Azimuth (degrees)	180	180	180
Tilt angle (degrees)	28	28	28
Yearly energy production (kWh)	11321	10662	Average: 10890 (11040; 10754;10876)
Difference with validation paper	4%	-2%	--
Average daily energy production (kWh)	31.0	29.1	29.8
Annual global radiation data kW/m2	1098	1014	Average: 1064 (1088; 1053; 1053)

Table 37 Validation solar panels

7.2 Heating

Validation programs

Two types of tools were used to validate the heat balance of the buildings. The tools (Enorm, 2016) and (Uniec 2, 2016) are both based on the NEN norm. Both tools provided different types of information and were used according to what part of the heat balance had to be validated. A building with different dimensions than the buildings in the case study has been simulated to compare the outcome of the model with Enorm. The dimensions of the test building are 12 m x 20 m x 10 m. Due to some limitations for input values in Enorm, the test building has been used to make a fair comparison.

Indoor temperature

For the transmission losses the example building has been used. Four different Rc-values for the insulation have been used to validate the model. It is explained that the set point temperature of the indoor temperature for residential building is 19 °C. However, it is more likely for a building which is poorly insulated, that the living room is 19 °C and the bed rooms have a lower temperature. This results in a lower average inside temperature. A correction factor is introduced in the NEN norm to compensate this. The average temperature ranges from 17 °C for a poorly insulated house to 19 °C for a newly built house (Spiekman, 2012).

This inside temperature has an important influence on the validation of the energy loss. In this research, all heat balances are modelled with a 20 ^{o}C inside temperature. This is a desirable temperature for buildings when they are well insulated and have constant heat transfer from the heat pump. The heat balances are also calculated for a lower average indoor temperature in order to validate this with the outcomes of Enorm.

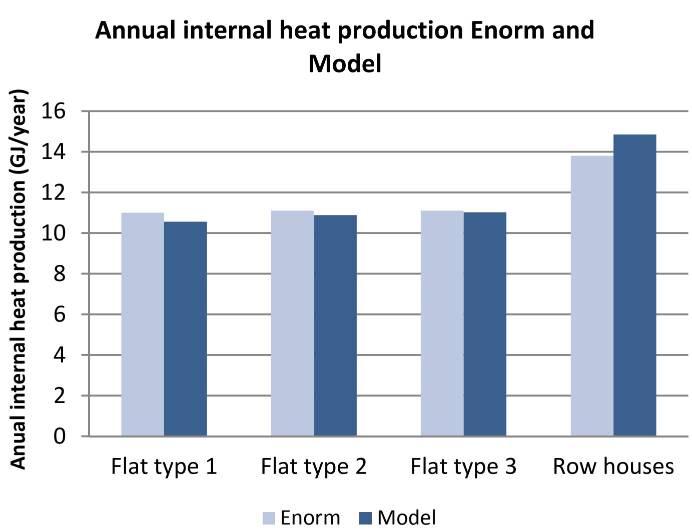

Figure 88 Annual internal heat production Enorm and Model

The model calculates the internal heat gain based on the appliances per m2 and number of inhabitants. The internal heat gain is very similar to the Enorm model for the flat apartments. The outcome of the model for the row houses deviate more than 30% compared to the Enorm. Enorm has a declining internal heat production per m2 with an increasing size of the apartment, while the model uses the same internal heat production per m2 for all sizes. Therefore, it is recommended to recalculate the internal heat production in the model when considering larger apartments.

Sun gain

Solar radiation heats up the building. The heat gained from the sun is compared with the outcomes in Enorm for three different solar heat gain coefficients. In Enorm the amount of solar heat depends on the U-value of the windows. This is not the case in the model.

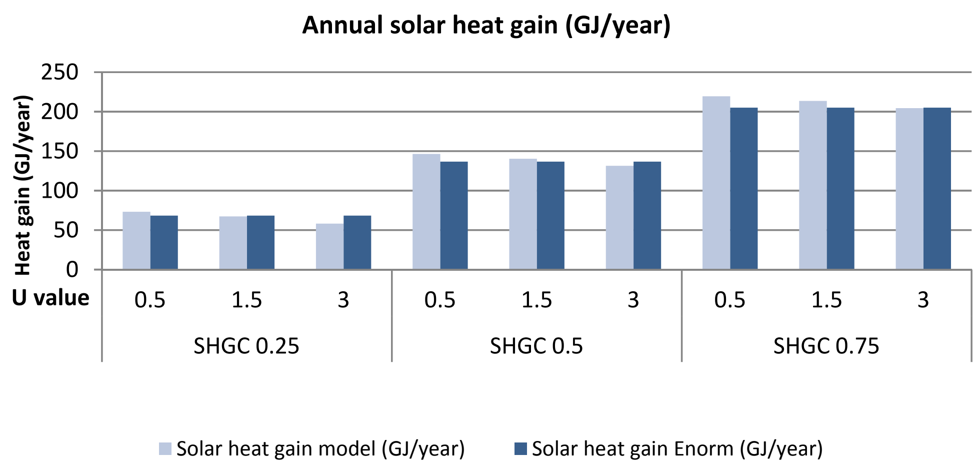

Figure 89 Annual solar heat gain (GJ/year)

The test model has been used to compare the outcomes. The building was oriented south north with 96 m2 windows on both sides; front and back side. For the model it is assumed that 80% of the solar heat enters the building. Figure 89 shows that the outcome of the solar heat gain in Enorm differs with each U-value of the window. Although this is not applied in the model, the outcomes are comparable.
This was also tested with the building is turned 45 degrees. The windows are north east and south west oriented. Also this shows similar results; the model resulted in a 7% higher outcome.

Infiltration + ventilation

The validation of the air streams infiltration and ventilation, consists of three parts. Firstly, it is checked whether with the same air streams, the heat loss is the same. Secondly, the amount of air is compared. Thirdly, the energy reduction of heat recovery is in both models simulated.

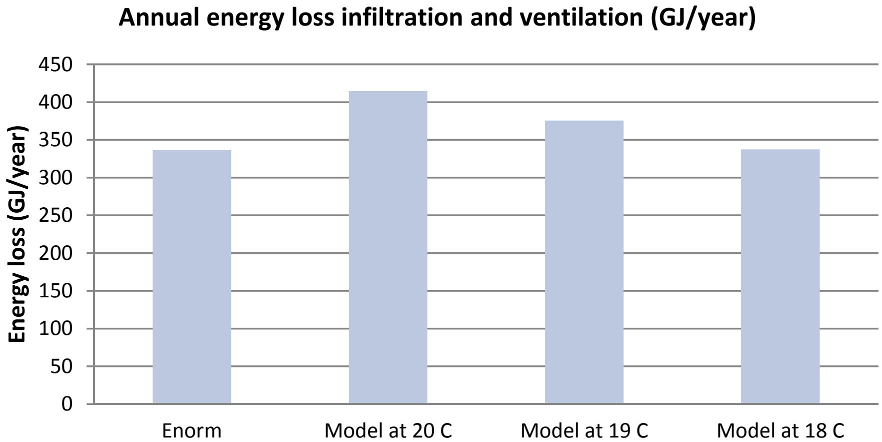

Figure 90 Annual energy loss infiltration and ventilation (GJ/year)

The example building has a volume of 2400 m3. The ventilation and infiltration rates that are used in Enorm are converted to number of air changes per hour. This air change rate is used as input in the model, resulting in a similar energy loss (W/K). Also the yearly energy loss of both models is compared. It shows that the energy loss for an inside temperature of 18 ^{o}C is about the same, while when using a higher indoor temperature the difference in energy loss between the model and Enorm increases. As described before in the validation of the transmission losses, the indoor temperature that is taken for Enorm will be around 18-19 ^{o}C. It is not likely that it has an indoor temperature of 17 ^{o}C since the example building as good insulation, a Rc-value of 1 (m^2k/W).

Next it is validated that with the same air changes rates the yearly energy loss is nearly the same, the next step is to compare the volume stream of air. Enorm bases the ventilation and infiltration rate on the area of the apartment. It also considers infiltration via the façade. No difference was made between these rates for a bad or a good insulated building.

The model in this research bases its ventilation rates on the number of inhabitants in an apartment and infiltration rate on the volume of the building. Because these air streams are calculated differently, the air stream is not the same in Enorm as in the model. It is described that the minimal ventilation rate is 25 m3/h per person (Bouwbesluit, 2016). Or depending on the area of the apartment, 0.7 dm3/s per m2.

	Current situation	Improved situation	Bouwbesluit (min 0.7 dm3/s*m2)
Building type	dm3/s	dm3/s	dm3/s

Flat type 1	47	50	46
Flat type 2	51	48	48
Flat type 3	52	49	48
Row houses	88	80	80

Table 38 Ventilation and infiltration rates

The air change rate is higher for the Enorm than in the model. The air change rates are hard to estimate since no detailed data is available for these buildings. Important is that the air change rate used in the model reaches the required air change rate by Bouwbesluit, which is 0.7-0.9 dm3/m2*s depending on the type of room. This required air change rate is higher in a room such as a toilet or lower such as a bed room.
The air change rates used in the model, just reaches the minimum. A higher air change might be required when taking into account the different functions of the rooms (De Vree, 2016). Also infiltration can be counted to the air change rate (Duijm et al., 2009).

Heat transmission losses

The Figure 91 shows that the yearly energy demand for the low quality insulation is comparable with the indoor temperature of 17 ^{0}C. With a Rc-value of 2 it shows similar results between 18 and 19 ^{0}C. For the best insulation the values are lower than the outcome of Enorm. This is due to the thermal bridges that are not taken into account in the model. Thermal bridges become more important when the insulation has a high quality. In this study, it is assumed that when the buildings are deeply renovated also the losses due to thermal bridges are reduced significantly. However, it shows that it is important factor when considering well insulated buildings. In future research the heat balance can be extended by including thermal bridges. It has to be noticed that the outcome of this model in the best insulating scenario could provide an underestimation of up to 25% in heat loss through transmission losses. The exact heat loss depends strongly on the building construction and the (improved) thermal bridges.

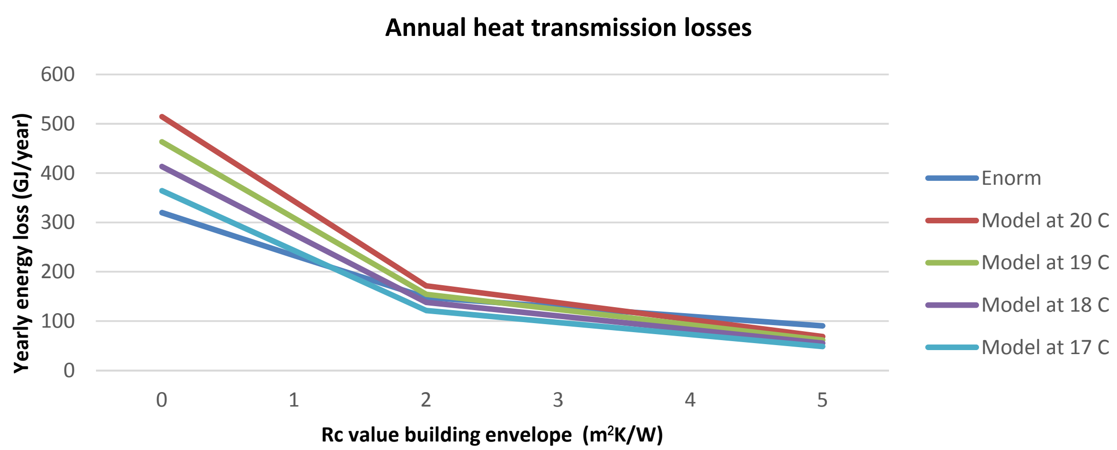

Figure 91 Annual heat transmission losses

Hot water demand

The hot water demand is calculated based on the area of the apartment when calculating it via the NEN norm. In this research the hot water demand is calculated per inhabitant. The results of the energy demand for hot water are compared. The results are very similar. The difference is that in the method based on the number of persons shows a different energy demand between the apartments in flat type 1, 2 and 3, while the NEN norm based on area of the apartment results is the same energy demand for these apartments (Van Oeffelen & Van Wolferen, 2012).

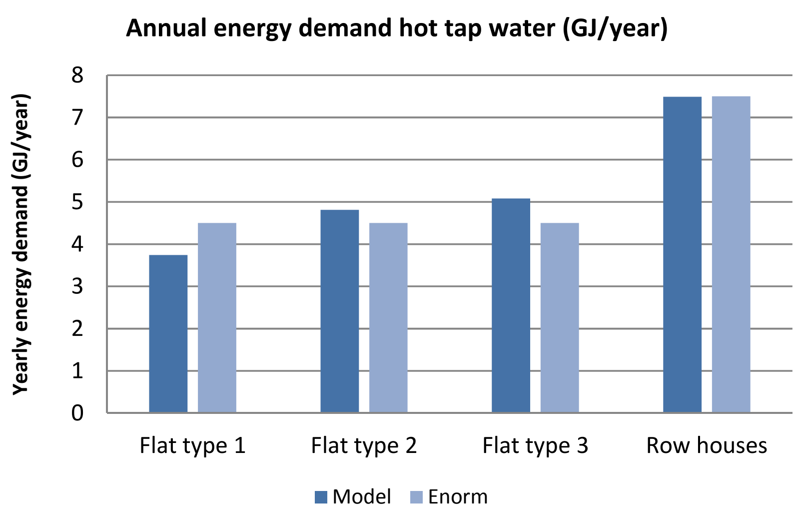

Figure 92 Annual energy demand hot tap water (GJ/year)

Solar boiler

With the collector oriented towards south tilt 45 degrees the same answer as the energy production for the row houses was found in Uniec. The reduction found was 4.4 GJ/year. When distribution losses for hot water are deducted, this results in 3.2 GJ/year, which is the production for a household with a hot tap water demand of 6 GJ/ year. This is according to the performance of the solar boiler.

Distribution losses

The same results were achieved with Uniec.

Heat pump

The primary energy of the heat pump was validated with Uniec.
Uniec calculates its primary energy demand via the following:

Primary energy (heat pump) = Heating demand/ (COP * ή electricity power plant) (25)

Uniec takes an efficiency of 39% of producing electricity in a power plant. In this research it is taken as 44%, according to (Gerdes et al., 2016).

Heat battery

The functioning of the heat battery was validated according to (Keizers, H., personal communication, December 2016).

7.3 Transport

The number of arrivals are compared with (R. A Verzijlbergh, Ilic, & Lukszo, 2011), which is based on Dutch average mobility data. The percentage of the number of arrivals for six different hours on a day are shown in Figure 93. The largest difference is in the evening rush hour. The dataset of RVMK provided arrival data for three periods: rush hour morning, rush hour evening and the remaining day. While assumptions were made about the rush hour in the morning, the data of the evening rush hour was not further adjusted. The main cause of the peak in the average Dutch mobility data in the evening rush hour was due to the high number of work (commute) trips (Harikumaran, 2012). The difference between the Dutch average and the data from RVMK could be explained by the fact that 29% of the trips of Dutch average have purpose work while this is only 18% in the area of the dataset. The assumptions that are made about the number of arrivals in the morning rush hour might be overestimated.

Another difference is that the number of arriving trips in the night is nearly zero for the Dutch average; this is also the case for leaving and arriving trips found in (Harikumaran, 2012). According to (Verkeer en vervoer, Gemeente Rotterdam) 10% of the trips on a working day happen between 23:00-07:00, which results in a higher value of arrivals during the night.

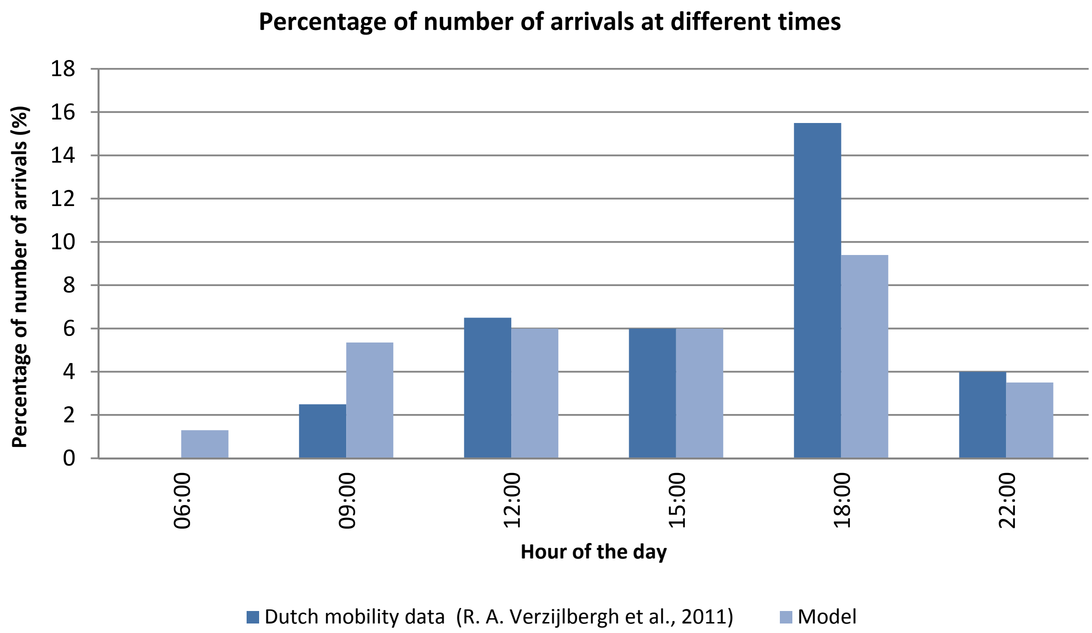

Figure 93 Number of arrivals cars

The power demand of uncontrolled EV charging in combination with a load profile of a household, was compared with (R. A. Verzijlbergh, Grond, Lukszo, Slootweg, & Ilic, 2012). The model was adjusted in order to compare it; aggregated load profiles were normalized to one household and EV's are charged with 3 kW.
In the research of (R. A. Verzijlbergh et al., 2012) charging takes place mainly in the evening and continues during the night, while in this research the peak load is more distributed over the day. As described before, there is a lower number of arrivals during evening rush hour in the case study neighbourhood than the Dutch average.

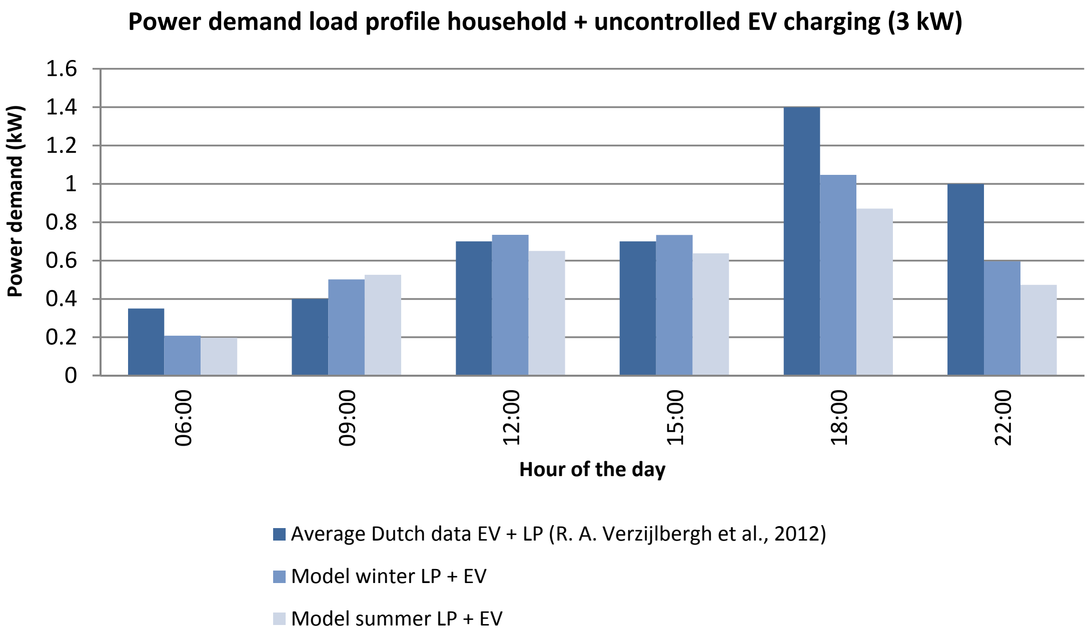

Figure 94 Power demand load profile household and uncontrolled charging of EV's

7.4 Scenarios

The peak demands for the different scenarios are compared with (B. Asare-Bediako, Kling, & Ribeiro, 2014). The number of households are scaled down to 200 in order to make a fair comparison. The average electricity demand is lower in the case study than average Dutch households. Therefore, the electricity load profile is increased to the same level as used in (B. Asare-Bediako et al., 2014). This research uses four type of buildings: detached, semi-detached, terraced (row house) and apartment. Detached and semi-detached building will have a higher heating demand than the row houses and apartments, which are the two types present in the case study. Therefore, the profile of the heat pump of the row houses are used to compare the peak demand, which is probably still lower than the average used by (B. Asare-Bediako et al., 2014). It is hard to estimate what the performance of the buildings that were modelled is. The average peak demand of the current and improved situation of the heat pump was used as to compare the results with. Figure 95 shows that the peak demands are very similar although there was only limited information available about the exact input values that were used.

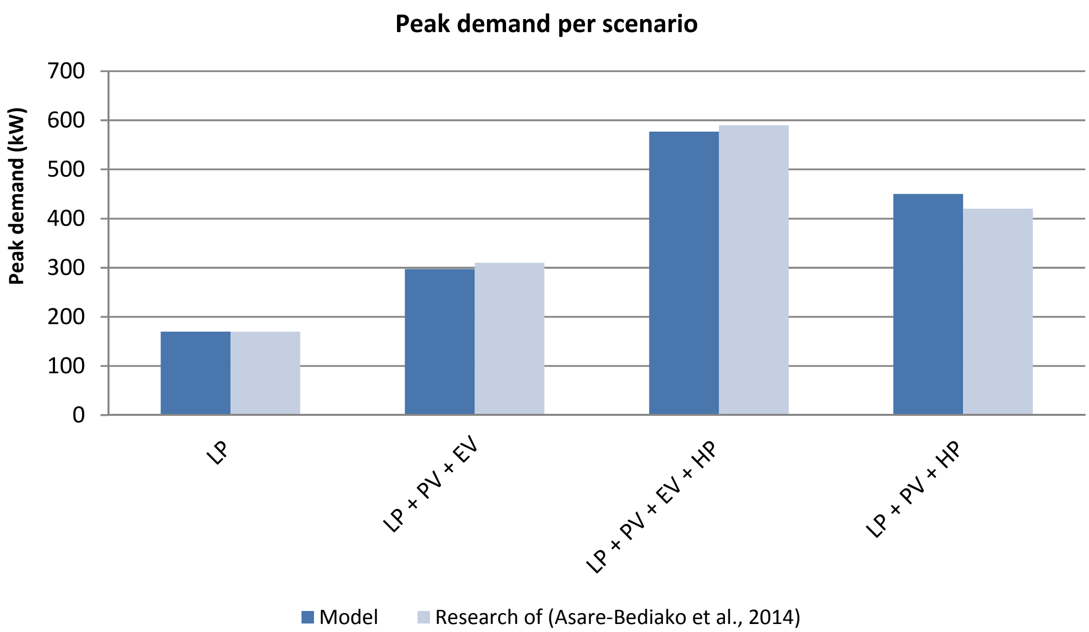

Figure 95 Peak demand per scenario

8 Results

8.1 Yearly energy demand

An overview of the improvements that are considered in this research is presented in Figure 96. The yearly primary energy reduction per measure is shown for each category (electricity, transport and heating). It has to be noticed that the difference in gas consumption and heat pump could even be larger because the gas scenario is modelled with an average lower inside temperature.

The different charging strategies represent only the energy that is needed in the neighbourhood itself to charge the cars. The total energy use per car for all strategies is the same as the home charging strategy.

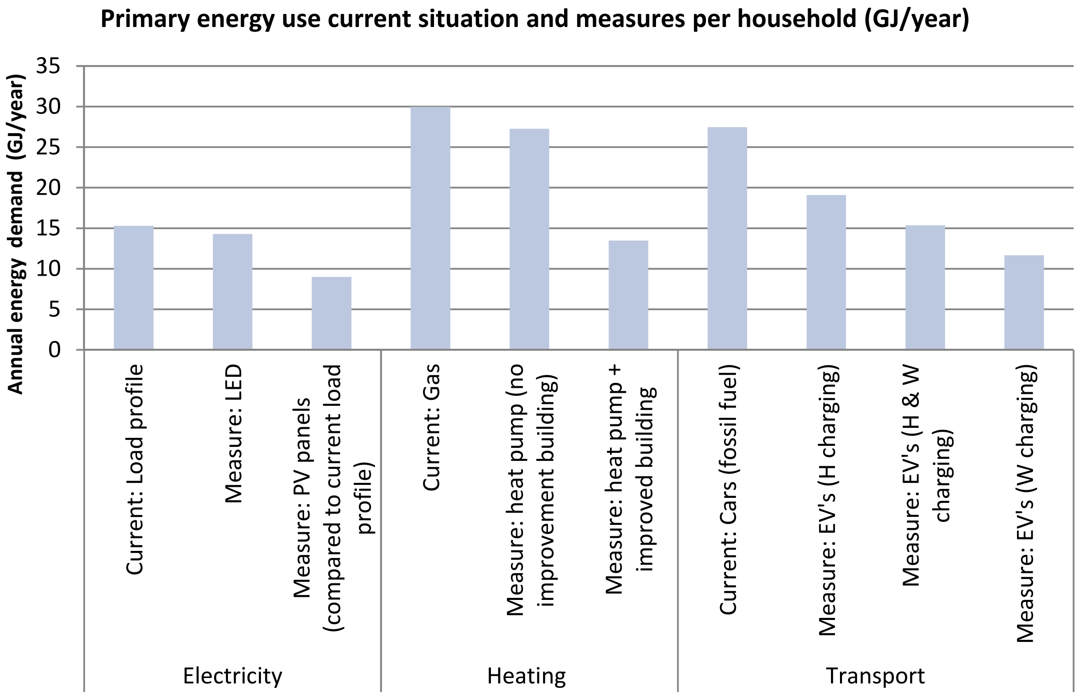

Figure 96 Primary energy use current situation and measures per household (GJ/year

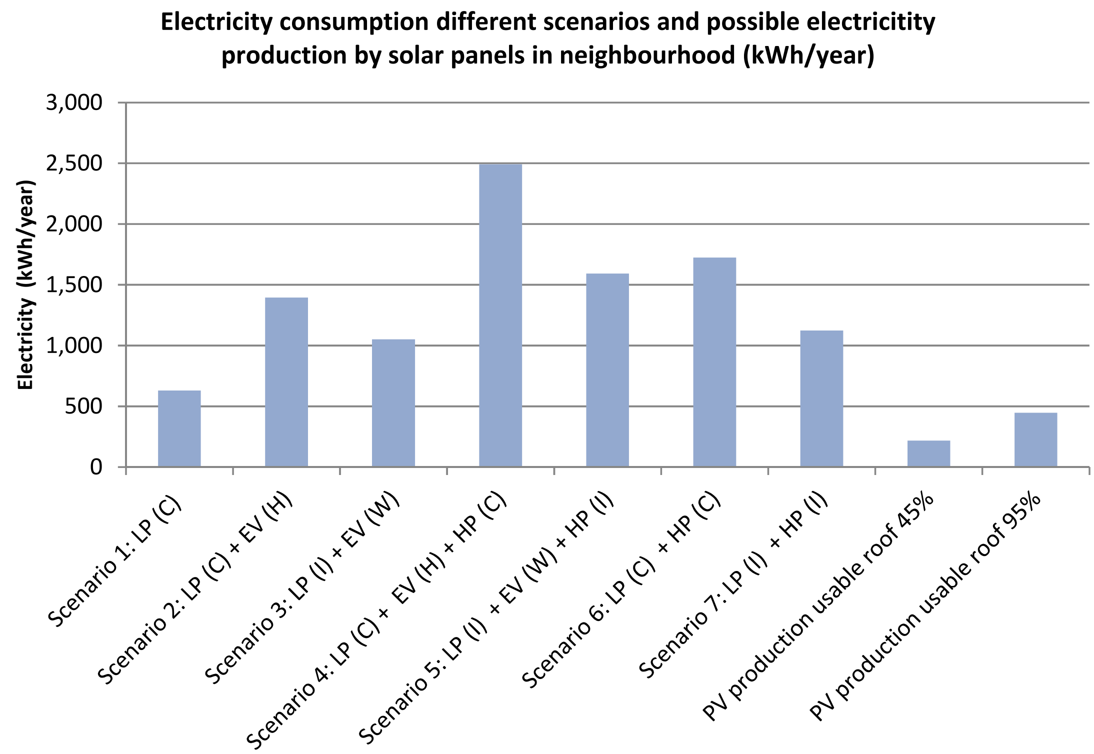

Figure 97 Electricity consumption different scenarios and possible electricity production by solar panels in neighbourhood (MWh/year)

Figure 97 shows the total yearly electricity demand of each scenario. Electric vehicles and heat pumps make it possible to replace natural gas and petrol with electricity. This could lead to enormous increase of electricity consumption when for example the energy performance of buildings in not improved. Only 45% of the roof could be used to install solar panels, which can just produce a small part of the annual electricity consumption. This is compared with a scenario where 95% of the roof could be used. Even a higher electricity production could be achieved when using the roof more efficiently for example with roof extensions or by mounting a tilted frame on top of the flat roofs (which reduces the distance between the panels).

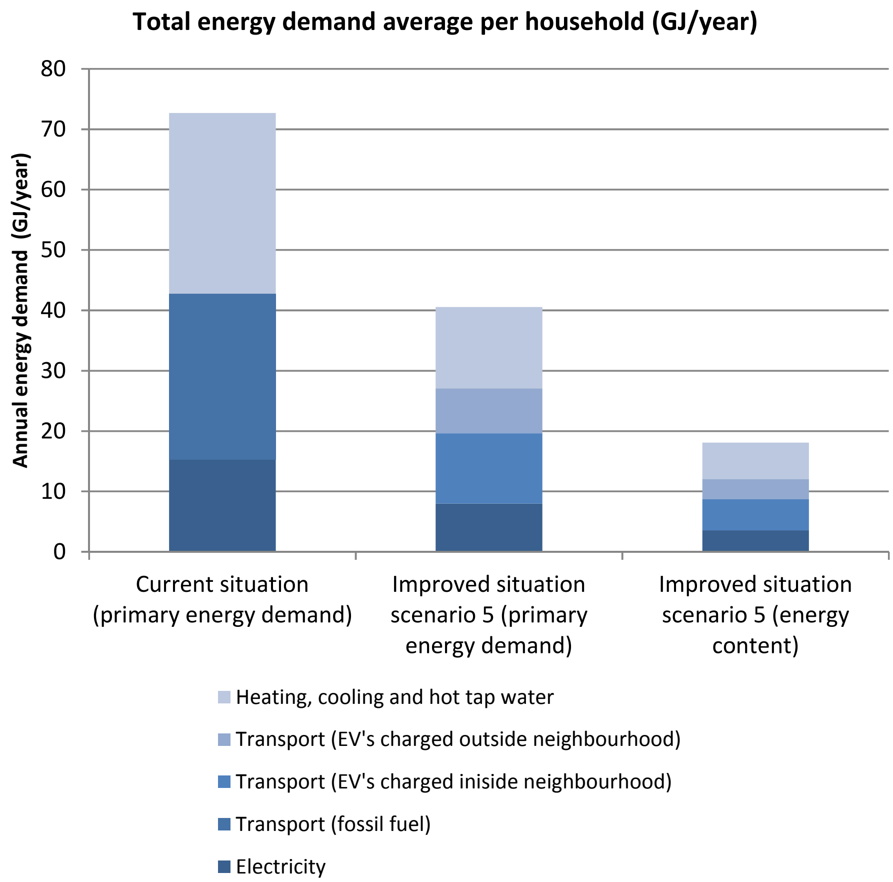

Figure 98 Total energy demand average per household (GJ/year)

Figure 98 shows the total primary energy demand of the neighbourhood in the current situation and the improved situation for scenario 5. Scenario 5 can achieve the highest reduction of primary energy demand of all scenarios, which is 45% compared to the current situation. Since only a part of the electricity demand can be produced on-site by solar panels, the remaining electricity demand needs to be "imported" from outside the neighbourhood. The share of renewables in the current electricity mix in the Netherlands is still very small. In case this would increase the primary energy demand of the neighbourhood can be reduced even more, shown in the scenario with energy content.

8.2 Scenarios

The scenario 4 and 5 are shown in Figure 99 and Figure 100 which include all different type of measures. A significant peak reduction can be achieved when applying charging strategy “at work charging” for electric vehicles and improvements are made in the energy performance of buildings. However, the overall electricity profile is still higher than the current load profile. A large peak can also be noticed during summer. This is due to the cooling of the heat pump, which has a lower COP than heating. More scenarios can be found in annex D.

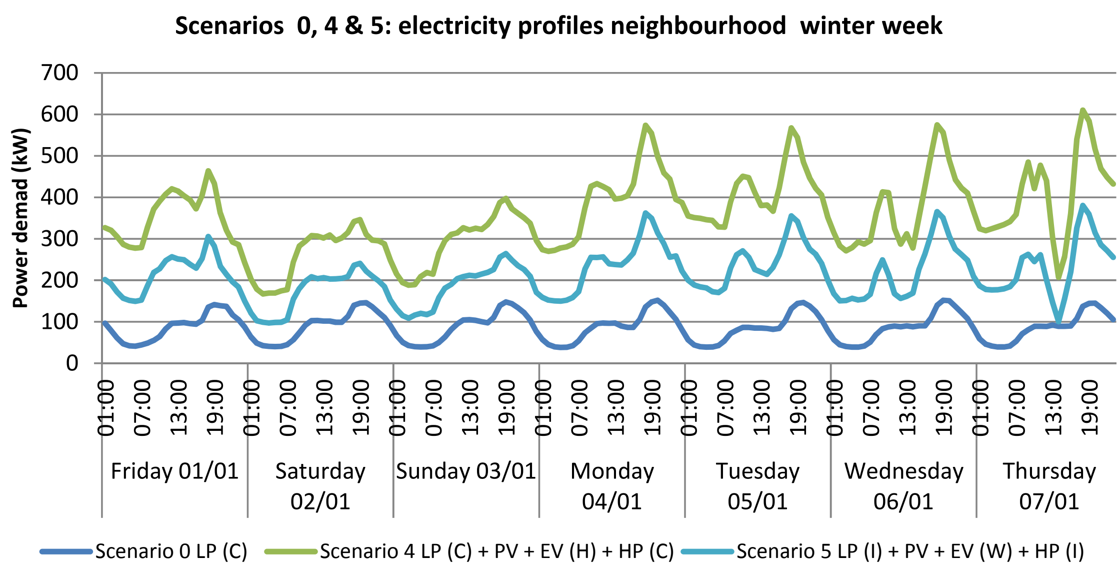

Figure 99 Scenarios 0, 4 & 5: electricity profiles neighbourhood winter week

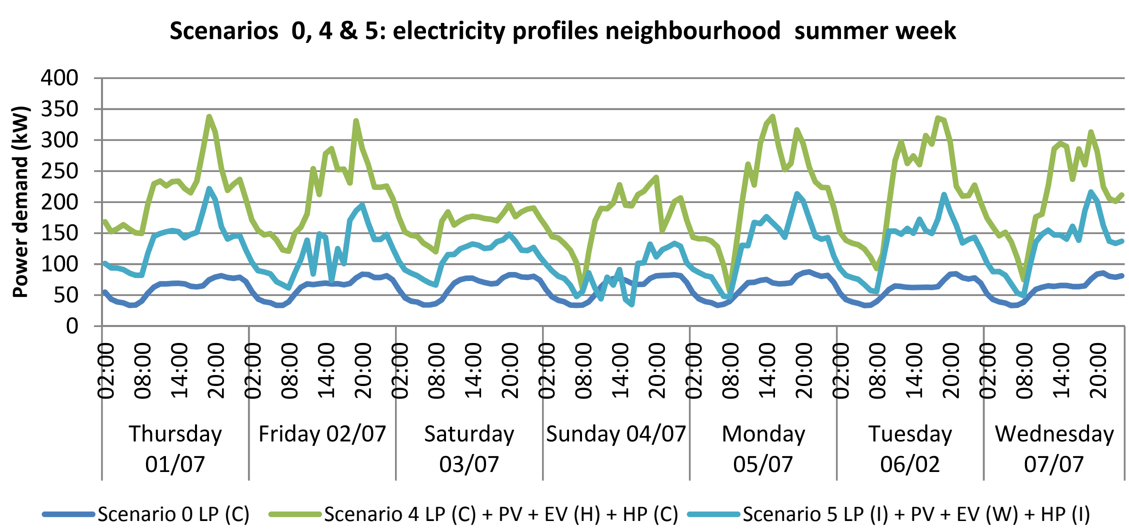

Figure 100 Scenarios 0, 4 & 5: electricity profiles neighbourhood summer week

The scenarios have different electricity profiles. Figure 101 shows the yearly average of how much of the electricity per hour is delivered by the grid. For example, when solar panels produce 20% of the electricity demand at 10 am and 40% at 11 am, the grid is averagely used 70%. Scenario 1 has nearly the same outcome as scenario 2 due to the fact that the electricity is not produced at the time that electricity is required.
The additional electricity demand in scenario 2 compared to scenario 1, is not at the same time as electricity is produced. This results in a similar outcome as scenario 1. When the produced electricity would be stored in battery, this could lead to a lower grid dependency. The Figure 101 shows that although the yearly primary energy demand is strongly reduced, the neighbourhood needs to electricity grid to deliver on average more than 80% of the electricity.

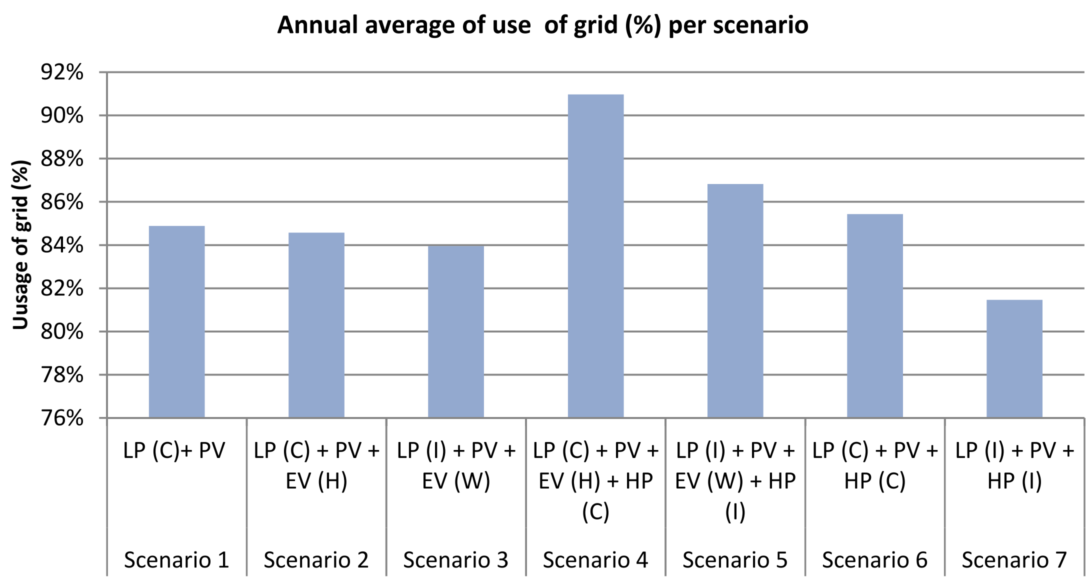

Figure 101 Yearly average grid use per scenario

8.3 Peak loads

The peak loads of each scenario are presented in Figure 102. It shows the day with the highest peak of the year. It has to be noticed that this is not always the same day for each scenario.
Detailed modelling is needed to estimate the local grid capacity of the neighbourhood. Therefore, a comparison is made between the scenarios and the highest peak load in the current situation. This is represented in the graph as a straight line. It is likely that there is additional grid capacity available, however it is not known how much this is exactly.
All scenarios exceed the current peak load.
Compared to scenario 4, which includes heat pump, electric vehicles and solar panels in the current situation, a significant peak reduction can be achieved by when applying the same technologies in the improved situation; scenario 5.

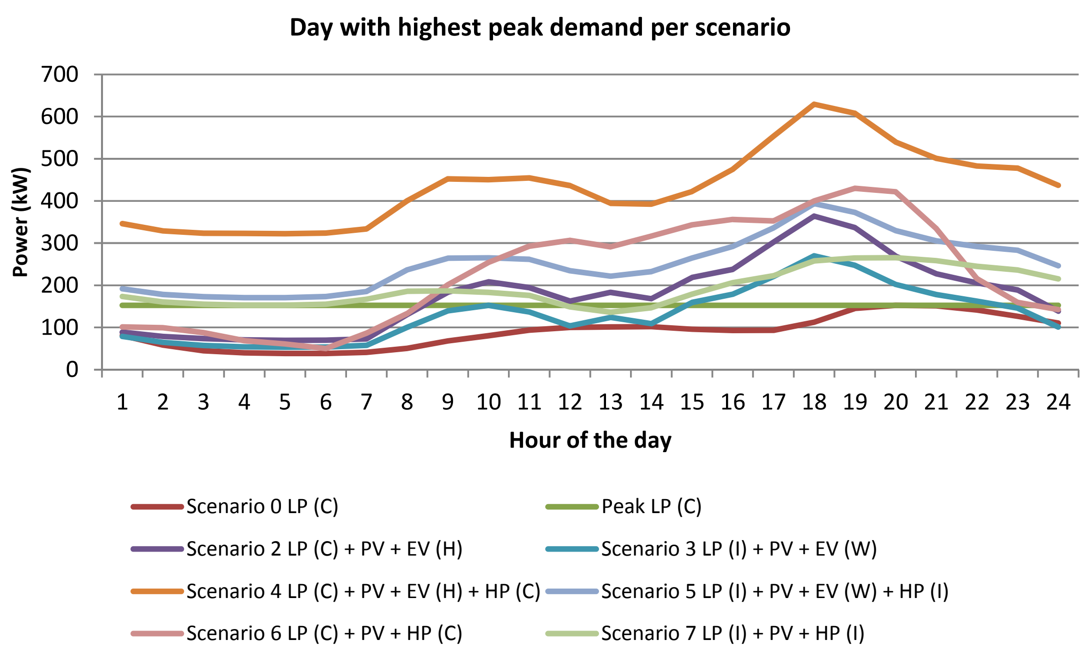

Figure 102 Day with highest peak demand per scenario

Scenario 5 achieves the highest reduction of yearly primary energy demand. Scenario 4 and 5 are compared with the current scenario in Figure 103. The peak demand of scenario 4 is 4.1 times the current peak demand, while scenario 5 shows a peak demand which is 2.6 times higher than the current scenario. This means that it is possible to reduce the peak demand with 40% by strong improvements in the energy performance of the buildings and implementing charging strategy at work charging for EV’s.
An average peak demand of the day with the highest peak of scenario 5 is represented as a straight line. The operation of the technologies could further optimized within the day of the highest peak load by shifting peak load in the evening to the night or morning. In case the peak demand is evenly distributed, it shows that it is still 1.7 times higher than the highest

peak load of the current situation. It depends on how much additional local capacity is available compared, whether this means that the current grid capacity needs to increase. For example, if the current grid capacity is dimensioned in such a way that it can handle 1.8 times the highest peak load of the current situation, than it is not necessary to reinforce the current grid.

It has to be mentioned that this is only the case when the operation is optimized and with the conditions that are used to model these scenarios. This implies in extreme conditions such as a very cold winter, the peak load could be much higher. At the same time, the average peak load could also be lower when operation is optimized over a larger period, such as three days. This makes it possible to reduce the peak load even more. For example, instead of charging all electric vehicles every, the charging could be spread out over three days according to the peak demand of other technologies such as a heat pump.

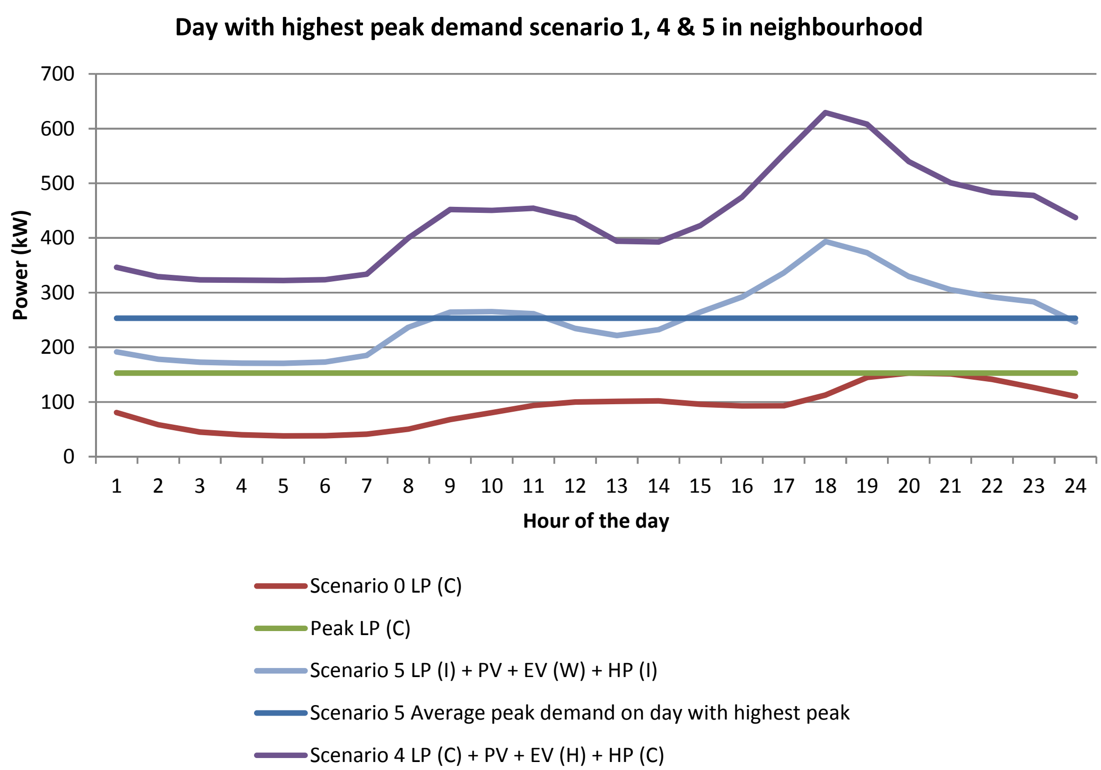

Figure 103 Day with highest peak demand scenario 1, 4 & 5 in neighbourhood

As described in chapter 6, the peak demand of the heat pump could be reduced with 10% in combination with a heat battery and a solar boiler. If a similar peak reduction could be achieved in the other buildings this could result in a peak demand which is 2.4 times the current situation. However, future research will be needed to explore the possibilities of a heat battery in a flat building.

8.4 Summary

It was shown that the primary annual energy demand in a case study neighbourhood could be reduced up to 45% with measures applied to heating, electricity and transport. Insulation is an effective way to reduce heating demand of buildings. The effect of energy reduction in the sewage system was very little, in contrast to LED street lights in combination with dimming. Due to the limited roof area, not enough electricity can be produced by solar panels in the neighbourhood to cover its own electricity demand. Independence of the fossil fuels gas and petrol was achieved by instalment of heat pumps and electric vehicles. However, this increases the electricity demand.

These new technologies stress the electricity grid due to the increasing fluctuations of demand and supply. These fluctuations can be levelled out first when using a microgrid, before interacting with the national grid.

In the worst case scenario an increase in peak demand of 4.1 times the current situation is shown. By improving the physical design variables in the built environment such as strong insulation, the peak demand could be limited to 2.6 times the peak demand in the current situation. If the operation of the systems could be optimized on the day with the highest peak, this could be reduced to 1.7 times the current peak demand.

Also the potential of seasonal storage in combination with a solar boiler has been explored. In this way, solar heat could be stored in the heat battery in summer and released in winter. An additional peak reduction of the heat pump operation could be achieved of 10% in a row house. This was not fully optimized, however it shows the potential in future.

9 Discussion

In this chapter the research and the developed model are discussed and placed in a larger context. The first part of the discussion focusses on more general aspects while the second part is on the model building itself.

9.1 General

Objective function

The focus of this research was on reduction of energy demand and increase in renewable energy production in the case study neighbourhood, the choice for a certain technique or modification of buildings will highly depend on the business case. This could vary per neighbourhood and per building. Other drivers are for example reduction of CO_2 emissions, comfort and impact on inhabitants and the role of involved parties. These factors are not considered but will play a major role in the decision making.

Applicability

The model was developed together with a case study. This has the advantage that real data can be used, which makes it very practical. Relations found between the buildings and their energy profile could be different for another neighbourhood. This depends on local parameters such as the type of building, current energy performance, type of inhabitants, location and climate. The results of the case study provide insights about important parameters, such as: the ratio between the number of households and the roof area. The impact of each parameter could be different for each neighbourhood or even building.
The improvements in energy performance of the buildings that can be achieved, could be more difficult to apply in some buildings more than others. This depends on the building construction and the room that is available for adjustments and installations. For example, heat recovery ventilation will require space for tubes to nearly all rooms. This might not be desirable in a small apartment due to the lack of space.

New neighbourhood

An existing neighbourhood was used to develop this model. The possibilities of improvements are limited. For example, it is not possible to change the orientation of the existing buildings. In contrary, when planning and designing a new neighbourhood, the choice for materials, installations, orientation and dimensions are not fixed yet. Because these decisions can be made in the planning and design phase, it makes it easier to build energy neutral compared to existing buildings.
This model could be used when planning and designing a new neighbourhood as well. The main difference is that most of the input parameters are not fixed yet which leaves more possibilities to match demand and supply with each other.

As described before, the ratio between the different measures could vary for different type and size of buildings. The main outcomes show that insulation and reducing energy demand are most effective. The size of the roof compared to the number of apartments is an important factor to determine to what extent the building is able to provide its own energy. The orientation of the building and the shape of the roof have influence on how solar panels could be placed and what the potential is for energy production. Seasonal storage can lower the peak heating demands in winter; this requires a large space for example in the basement.

Scale is key

The measures that can be applied in a case study to become energy neutral depend on the scale. When considering a single apartment, the measures might be limited to increase the energy efficiency of appliances and lighting and improve insulation. When the energy balance of the city is considered, for example transport can be improved by stimulating biking and use of public transport. It can be stated that the scale of the considered area is key regarding what measures can be applied to improve the energy performance of this area. This research is focussed on a neighbourhood and the possible measures on this level. This means that the potential of improving the energy performance might be larger than shown in this research when extended to city or national level.

Difference in type of people

In this research the energy performance of the neighbourhood is mainly based on building parameters and other static data. The socio-demographic backgrounds of the inhabitants are not considered but could have a major influence on when and how much energy is consumed. For example, elderly retired people are more often at home and prefer a higher room temperature than young professionals without children. Also the interaction between the user and the technology has an effect on the actual energy consumption. For instance, a ventilation system with heat recovery might be the optimal way to conserve the cool air in the building during summer. It might happen that the inhabitants like to open the windows to experience the nice weather, which is not beneficial for the energy demand of the cooling system.

Data

This model requires many datasets, which are not always available or requires extensive effort and time to process. The quality of the output of this model is highly dependent on the quality of the input. It is difficult hard to model the exact energy performance of a neighbourhood, which has two main reasons. Firstly, it is dependent on very local and specific data such as the energy performance of buildings, which has a limited availability. Secondly, user behaviour has a large influence on energy demand. Even when the energy performance of a building is exactly modelled, user behaviour increases the uncertainty of the outcome.

Many assumptions had to be made in this model. Since it consists of many sub models, the assumptions could be added up resulting in an extreme outcome or the opposite could happen; the sub results can level each other out.

The importance of local data is shown in this research when modelling a specific neighbourhood. It was shown that its energy profile could be very different from average Dutch data. However, it will not always be possible to gain more detailed data due to privacy reasons.

9.2 Limitations model

Applicability

Because this model was developed together with a case study neighbourhood, the model will need adjustments before applying it to a different neighbourhood. For instance, in the current case study all buildings have a cubic form or a cubic form with a gable roof. A more complex form is not included in the model; it is certainly possible to add this.

Electricity

The data that is available about the annual electricity demand of the households was collected on zip code 6 level (Hofgärtner, 2016). It is assumed that this includes electricity use of building specific loads such as elevator, installations, lighting in the staircases. These loads are assumed to be constant although the building installations were changed. Excepted is the electricity use of the heat pump, since this is such a great part of the total electricity consumption.
The load profiles of the electricity demand that are used are average Dutch profiles. These profiles could be different in the case study if the inhabitants are not representative for the Dutch population, for example due to variation in social-economic backgrounds.

Heating

Modelling the energy performance is very challenging since there are many factors that have a major influence on the outcome. This means that there is a high uncertainty in the heat balances of the building. Since the energy performance of each building is different, it is very difficult to gain information and therefore many assumptions had to be made about it. For instance, two buildings with the same insulation value could have a different heating demand due to local leakages or thermal bridges. A check of energy status of each building would be needed to gain the right inputs. On top of that, this model does not include the effect of thermal mass and thermal bridges or shadow casting on windows by specific shapes of the façade. Also heat losses during distribution are modelled very simple. These depend on the exact configuration of the heating system in the building such as the length of the pipes and its insulation, the location of the installations or the location of hot water use. Additionally, the performance of the solar boiler is modelled very simple. The thermal losses are assumed constant during the year. This might give an overestimation during colder days and an underestimation during hot days.
Furthermore, the operation of the heat pump is not optimal. Sometimes the heat pump cools and heats during one day. This might require more energy than actually needed. The required room temperature is taken as a constant in this model. This is preferable for a well-insulated building, because the power demand of the heat pump is relativity constant. In the current situation of the buildings, it would be more likely that the heating system is only turned on when the inhabitants are at home. Therefore, the energy demand in the current situation might be overestimated.

The model is adjusted to the gas consumption data that was gained. It has to be noted that there is a high uncertainty in the actual gas demand among some buildings. The data gained for flat type 1 is relatively reliable because it contains many apartments. The other three types of buildings are less reliable (Hofgärtner, 2016).

Transport

Many assumptions had to be made in the analysis of the driving patterns by the inhabitants. Firstly, not all trips were carried out by the inhabitants of the case study; the provided dataset contained data of a larger area. An estimation had to be made to distribute the trips among the inhabitants of the case study and the remaining functions in the area. Secondly, no difference was made in the number of trips, the driven distance and the number of cars among the households in the case study. This resulted in average numbers. It is likely that these numbers are more distributed. For example, a household of one elderly person and a household of a family with three children have a different driving pattern. The family might cover a larger distance per day, carry out more trips and own more cars than the household of one old man. When more distributed profiles would be used this could lead to more fluctuations in the charging profile.

A third assumption has been made about when the cars are charged. It is assumed that this is one time a day, distributed according to the number of arrivals per time period. It would be more likely that inhabitants charge their car according to the state of charge of their car, which is not taken into account in this research. For example, it could happen that the inhabitants charge their car every third day, also resulting in more fluctuations of the charging profile. However, the total amount of energy required would not change because of a different charging pattern.

Another assumption regarding the charging strategies had to be made due to lack of information; the number of trips per day for a car used to drive to work and a car not used to drive to work is equal. Also this could be differently distributed. For example, a car that is used to drive to work might make more trips (shopping, leisure time, etc.) on a day than a car that is not used to drive to work. The household that does not use their car to drive to work might use different ways of travelling to get around (public transport, cycling, etc.).

Finally, the data that were used for the ownership of cars per household, is doubtful. Two different sources provided different values. If a lower number of cars per household was chosen, it would result in a higher ratio of cars used to drive to work compared with cars that are not used to drive to work. As a consequence, more cars could charge their car at work in the researched charging strategies.

10 **Conclusion**

The goal of this research was to find how an existing neighbourhood could become energy neutral neighbourhood using a microgrid. The most influential factors in the relationship between energy and the built environment were found in order to combine these two sectors. Simplified sub models were used to cover this large topic.

First, different ways of approaching an energy neutral neighbourhood were compared in order to come to an integral approach. Approaches on four different levels were analysed, which are: microgrid, building scale, urban scale and policy level.
Various measures can be applied to reduce the primary energy demand of the neighbourhood. Although emerging technologies such as electric vehicles and heat pumps, could improve the annual energy demand, it can increase peak demands in the electricity grid when considering a smaller time step. The electrification of such technologies make the heating and transport become more connected with the electricity sector.
The electricity profile of heat pumps and electric vehicles is strongly related to the physical variables of the built environment. Measures in the neighbourhood, such as insulation, can reduce peak demands and facilitate better matching of demand and supply.

Secondly, existing tools for energy neutral neighbourhoods were evaluated based on different variables: scale, time step, time horizon, type. The choice for each of these aspects depends on the purpose of the application. The building and energy sector can be combined by using two different type steps. An annual time step is used to show the influence of an improvement in the neighbourhood. This could be switching from gas heated buildings to heat pumps or the replacement of fossil fuel cars by electric vehicles. At the same time, an hourly time step can cover for example the fluctuating energy production from renewable sources. A time horizon of one year is used to include differences in solar radiation and outside temperatures of all seasons. Scenarios can provide more insight on the influence of various parameters.

In conclusion, the different approaches can be integrated by merging planning on urban level, designing of buildings and operation on energy system level into one model. This model covers heating, cooling, electricity and transport, taking into account the impact of measures on the annual and hourly energy balance.

The scale of the neighbourhood allows to simplify the sub models; the urban and building scale were connected by using a top down and bottom up approach. Individual data was merged on building level. This means that individual energy profiles were levelled out but still the difference between the building types could be shown. The same applies for the heat balance; this was modelled on building level instead of each single apartment.
The mobility patterns were considered on the scale of the neighbourhood, leaving out individual movements. Although a simplification was made for these sub models, a difference was shown between the case study neighbourhood and Dutch averages.

This model was developed together with a case study in Rotterdam. The model could be applied to other existing neighbourhoods as well. However, this model requires many data inputs, which makes the quality of the outcome dependent on the quality of local available data. A challenge it to estimate the current energy performance of an existing neighbourhood.

In this research about how an existing neighbourhood could become energy neutral using a microgrid, an integral approach was used to explore the relationship between the built environment and energy sector. It was shown that the primary annual energy demand in a case study neighbourhood could be reduced with 45%, with measures applied to heating, electricity and transport. Insulation is an effective way to reduce heating demand of buildings. The effect of energy reduction in the sewage system was very little, in contrast to LED street lights in combination with dimming. Due to the limited roof area, not enough electricity can be produced by solar panels in the neighbourhood to cover its own electricity demand. Independence of the fossil fuels gas and petrol was achieved by instalment of heat pumps and electric vehicles. However, this increases the electricity demand.
These new technologies stress the electricity grid due to the increasing fluctuations of demand and supply. These fluctuations can be levelled out first when using a microgrid, before interacting with the national grid.
In the worst case scenario an increase in peak demand of 4.1 times the current situation is shown. By improving the physical design variables in the built environment such as strong insulation, the peak demand could be limited to 2.6 times the current situation. This is a peak reduction of 40%.
Also the potential of seasonal storage in combination with a solar boiler has been explored. In this way, solar heat could be stored in the heat battery in summer and released in winter. The peak demand of the heat pump could be reduced with 10% in a row house. This was not fully optimized. For example, the average peak reduction of the operation of the heat pump in a winter week was 17%. This shows the potential in future.
In this research it is shown that the different measures that can be taken are not only the sum of adjustments, but have a larger effect on each other. For example, when applying strong insulation this reduces the annual heating demand. A secondary effect is that it could also reduce peak demands when it is combined with a heat pump, which could limit the costs of adjusting the grid.

In further research, optimization of operation of the technologies could be lead to an additional decrease of peak demand. Additionally, by including costs this could provide more insight in the economic value of reinforcing the grid and investments in the built environment. Finally, it is recommended to explore the influence of user behaviour, since this could play a substantial role in energy profiles.

11 **Recommendations**

The scope of this research is limited. Therefore, a list of recommendations is given below that could be used for further research.

Costs

A major driver behind the transition towards energy neutral neighbourhoods is costs. The implementation of the chosen techniques and improvements will depend on the investments and operational costs and the price of energy. The costs aspect is not considered in this research; nevertheless, this is an important factor in the transition towards an energy neutral city. Questions rise such as: can the building owners afford such investments or, will the costs of housing (rent and energy bill) for tenants stay the same?
If this model would be extended with business cases, it is important to use an integral approach as well. Instead of making a business case only for the building owner and user, also the business case of energy infrastructures could be included (Hofgärtner, 2016). Although the costs for example of reinforcing the electricity grid are not always directly charged to the user in that area, it will raise the socialized costs.
In order to compare different type of energy systems such as district heating and all-electric, the whole costs chain needs to be considered. Costs of a new energy system and improvements in energy performance of buildings depend on economics of scale, subsidies, alternatives, policy on national and city level, etc.

This research could be extended with an optimization model. This allows finding an optimal scenario regarding the energy profile, costs and possible CO_2 emission. In an optimization model also operation could be adjusted to the price of energy. For example, the heat pump can start heating the hot water storage tank or the heat battery when the electricity prices are low. Also in an optimization model, it is important to keep the relation with the overall context such as the energy improvement on a yearly basis compared with other measurements.
It is recommended when building an optimization model in excel, to include this from the beginning of the development of the model. This determines the functions used in the model and the overall structure.

Scale

There are many possibilities to improve the energy balance on neighbourhood level. These are not the only improvements that can be made. Further research on a larger scale could contain energy reduction by decreasing the use of cars by stimulating public transport, cycling or walking. The built environment and transport are often seen as two separate challenges, but are more closely related if electric vehicles are included. Further research on a lower level could be applying to different load profiles of households as described before. The use and type of appliances and lighting that are present in different type of households.

Model

The model that was developed in this research requires a lot of data that needs to be manually entered. A more advanced model could be developed that integrates the input from GIS maps and databases with a 3D model into one model. This can reduce the time that is required to enter all information in the model and it can be plotted for the whole city. Then it can show the potential of various types of measures and its impact for different types of buildings and neighbourhoods. This information can be used to make an energy strategy on city level.

Excel model

It was chosen to develop this model in Excel, because it is generally available, which makes it easier to share. However, the user-interface is very minimal. A more user friendly interface would be preferred when sharing it among others. The excel model in the current state, has reached almost its limit in the overall structure, the ease of modelling and adjusting. An efficiency step would be required when continuing in this model. This could be by using "queries" in excel, which allows running formulas in a more structured way. An alternative option is to use a coding program such as Matlab. The drawback is that these type of programs require more time to understand for untrained users and are not always available.

Differences in energy profiles

As mentioned in the discussion, social-economic and demographic factors such as income, age, education, employment etc. are not taken into account in this research. However, this could have influence on the energy profile of the neighbourhood. For example, on driving patterns, type of appliances present in the houses or when energy is consumed. This is important for the sizing of the energy system since energy consumption is related to human behaviour.

Functions

Initially, it was planned to include other functions besides dwellings in the case study. Due to lack of data about the energy performance of these buildings, these were left out. However, the mixture of different functions in a neighbourhood could have the potential to smoothen out the energy profile. For example, the electricity produced during day time by solar panels on top of the dwelling buildings, could be used by shops or offices close by. This way, the required energy storage could be decreased.

Buildings

The data that was available about the energy performance of the buildings was limited. Also the uncertainty factor is relatively larger since the actual energy performance and the possible improvements can be different for each building, as described in the discussion. Energy reports are being made of the existing building stock. In closer collaboration with housing corporations or building owners associations, more detailed research can be carried out.

Heat battery

The functioning of the heat battery in a row house was shown. This could play a larger role in the reduction of peak demand. However, this was not fully explored in this research. Many variables could influence the operation of the heat battery. The current model leaves a great potential for further optimization.
Seasonal storage could also play an important role when dynamic electricity and heating prices are introduced. In this model, heat was stored only when the solar boiler produced excess heat. In case abundant electricity is produced and the electricity price is very low, even a heat pump could be used to charge the battery. Also during winter time, the heat battery can be used according to the electricity prices. The heat pump provides heating when the electricity price is low while the heat battery releases heat when the electricity price is high.
An advantageous effect of seasonal storage is that the heating systems can be sized smaller because the heat battery can take care of the peak moments in heating demand.
In this research, the heat battery is only used for heating. However, it is possible to use this concept in a slightly different configuration also for cooling.

Transport

The driving patterns and the charging patterns of EV's were not modelled on a very detailed level containing for example driving range of the car or state of charge of the battery. As described in the discussion also many averages had to be used, while there could be a wide distribution in mobility patterns, car ownerships and charging behaviour.
The mobility model (RVMK) of the city of Rotterdam is very extensive. However, the current data set provides information about the number of trips arriving and leaving the neighbourhood and the purpose of the trip. For instance, it is uncertain if one car arrives five times in the neighbourhood or five cars arrive one time each.
More accurate and detailed data of unique cars would be needed to analyse separate moving patterns and estimate charging profiles. For example, by testing a neighbourhood with real time mapping of driving patterns of inhabitants to gain more information about the number of trips per car, the purposes and distance per trip, the duration of parking, etc.

Roof

Local energy production is an influential factor to what extend a neighbourhood could become energy neutral. It was shown that the roof was the limiting factor in the distributed energy production of electricity and heat. In this research less than half of the roof was considered as possible area to install solar panels and boilers. However, the potential might be larger. The usable roof area can be increased with roof extensions or an additional frame to cover the installations and chimneys present on the existing roof. Also solar panels in the façade or covering parking spots could increase the potential for energy production even more.

Shadow

It was difficult to find a program that could model shadow factors on an hourly basis. Finally, the shadow factors were manually gained from a Sketchup 3D model. These are static factors, meaning that when dimensions of buildings change in the model; these do not influence the shadow factors. Modelling this is complicated since it depends on the locations that the buildings have regarding each other and the sun position. Nevertheless, this could provide very valuable information. Shadow does not only affect the heat balance of the buildings, but also the potential to produce energy by solar boilers or panels. Especially, in an urban environment with a high density, where roof area is limited, this is a determent factor to what extend the neighbourhood can become self-sufficient in its energy use.

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12.1 References personal communication

De Voogt, K., December 2016
Information manager, Municipality of Rotterdam

Knap, W., September 2016
Research Scientist, KNMI

Keizers, H., December 2016
Programme Manager Energy Built Environment, TNO

Kemeling, A., December 2016
Advisor sewage systems, Municipality of Rotterdam

Van der Linden, L., December 2016
Advisor Urban water systems, Municipality of Rotterdam

Van Rijthoven, R., October - December 2016
Traffic engineer, Municipality of Rotterdam

Vermeulen, K., December 2016
Constructor, Municipality of Rotterdam

Wijnands, P., December 2016
Maintenance, Municipality of Rotterdam

13 **Appendix**

Appendix A: Overview of analysed tools
Appendix B: Overview of data
Appendix C: Calculations
Appendix D: Additional graphs

A. Overview of analysed tools

Name tool	Developers tool	Website
CitySim	Solar Energy and Building Physics Laboratory (LESO-PB), Ecole Polytechnique Fédérale de Lausanne (EPFL)	http://citysim.epfl.ch/
DEECO	Institut für Energietechnik, Technische Universität Berlin	http://www.iet.tu-berlin.de/deeco/
Effort	Fachhochschule Nordhausen University of applied science, JENA-GEOS Ingenieurbüro	http://www.unternehmen-region.de/de/7701.php
EnergyPLAN	Aalborg University	http://www.energyplan.eu/
EnergyPlus	the U.S. Department of Energy and the U.S. Department of Defence.	http://apps1.eere.energy.gov/buildings/energyplus/
H2RES	Instituto Superior Técnico and the University of Zagreb	http://powerlab.fsb.hr/h2res/
HOMER	National Renewable Energy Laboratory in the USA and HOMER Energy LLC	http://www.homerenergy.com/
Inforse	International network for sustainable energy	http://www.inforse.org/europe/Vision2050.htm
LEAP	Stockholm Environment Institute	http://www.energycommunity.org/
MARKAL/TIMES	Energy Technology Systems Analysis Program, International Energy Agency	http://www.etsap.org/
RETScreen	National Resources Canada RETScreen International	http://www.retscreen.net/
TRNSYS	The University of Wisconsin Madison	http://sel.me.wisc.edu/trnsys/

Table 39 Overview of analysed tools

Tools	D. Connolly et al. (2010)	D. Markovic et al. (2011)	M. Manfren et al. (2011)	G. Mendes et al. (2011)	Allegrini (2015)	Darren Robinson (2009)	Huang (2015)
CitySim						x	
DEECO		x	x				
Effort							
EnergyPLAN	x	x	x				x
EnergyPlus		x	x		x		
H2RES	x			x			
HOMER	x	x	x	x	x		
Inforse	x						
LEAP	x	x	x				
MARKAL/TIMES	x			x			
RETScreen	x	x	x	x	x		
TRNSYS	x	x	x		x		

Table 40 Literature used per tool

B. Overview of data

Enorm

Energy modelling software based on NEN, http://dgmrsoftware.nl/enorm.php, 2016

Gemeente Rotterdam

BAG panden, dimensions buildings, in ArcGIS, 2016.

KNMI (this data set was not used in the final model)

Two type of data sets were used, both from KNMI from the year 2010. The ambient temperature was taken from the weather station in Rotterdam. The radiation data were used from the CESAR database. In contrary to data from Rotterdam where only global radiation data was measured, this database provides also diffuse and direct radiation data.

NEDU

Average load profiles, Nedu.nl , 2016.

NEN 5060
Hygrothermal performance of buildings - Climatic reference data, table A2, 2008.

Overmorgen

Data about car ownership was collected in order of Gemeente Rotterdam, 2016.

RVMK

RVMK Regionaal Verkeersmodel 2015, department Verkeer & Veroer, Gemeente Rotterdam.

Uniec 2

Energy modelling software based on NEN, http://uniec2.nl/, 2016

Verkeer & Veroer, Gemeente Rotterdam

Busyness measurements on the roads and ratios for “stadswegen”, department Verkeer & Veroer, Gemeente Rotterdam, 2015.

C. Calculations

Sun simulator

The sun simulator that is included in this model gives the hourly position of the sun. This varies during the day (the sun rises in the east, goes down in the west) and the year (the sun is higher and longer in the sky in summer than in winter). How the position of the sun is modelled is described in below, according to (Jäger et al., 2014).
The neighbourhood is located in the Rotterdam, the entered location data are

ϕ_o = latitude = $51.941\ N = +51.941\ [N = +, S = -]$
λ_o = longitude = $4.552\ E = +4.552\ [E = +, W = -]$

Time D are the number of days that are passed since noon on 1st of January 2000 in Greenwich. The latitude of the sun λ_s and longitude β in ecliptic coordinates are given below. The mean longitude q and mean anomaly g of the sun, are normalised to the range 0 till 360 degrees.

$$\lambda_s = q + 1.915° sin(g) + 0.020° sin(2g) \quad (26)$$

With
$q = 280.459° + 0.98564736° \cdot d$
$g = 357.529° + 0.98560028° \cdot d$
$\beta_s = 0$

The axial tilt of the earth ϵ is used to transfer the ecliptic coordinates to equatorial coordinates.

$$\epsilon = 23.429° - 0.00000036° \cdot d \quad (27)$$

To compute the local mean sidereal time, θ_L, Greewich Mean Sidereal Time (GMST) is used of which the outcome is normalised to the range 0 till 24 hours.

$$\theta_L = GMST \cdot \frac{15°}{hour} + \lambda_o \quad (28)$$

With: (29)

$$GMST = 18.697374558 \cdot h + 24.06570982441908 \cdot h \cdot d + 0.000026 \cdot h \cdot \left(\frac{d}{36525}\right)^2$$

These values provide the input for calculating the solar position azimuth A_s and altitude a_s:

$$tan(A_s) = (-sin(\theta L) * cos(\lambda s) + cos(\theta L) * cos(\epsilon) * sin(\lambda s)) / (-sin(\phi o) * cos(\theta L) * cos(\lambda s) - (sin(\phi o) * sin(\theta L) * cos(\epsilon) - cos(\phi o) * sin(\epsilon)) * sin(\lambda s)) \quad (30)$$

$$sin(a_s) = cos(\phi o) * cos(\theta L) * cos(\lambda s) + (cos(\phi o) * sin(\theta L) * cos(\epsilon) + sin(\phi o) * sin(\epsilon)) * sin(\lambda s) \quad (31)$$

In order to provide values between 0 and 360 degrees, the arctan function needs an adjustment due to some ambiguities. Therefore the function is:

$$arctan\, f(..) + n * 180° \quad (32)$$

With n depending on the numerator N and the denominator D:

$N \cap D > 0 \rightarrow n = 0$
$N < 0 \rightarrow n = 1$
$(N > 0) \cap (D < 0) \rightarrow n = 2$

Radiation

The energy produced by solar panels depends on the global irradiance I_{glob} that falls on the panel. The global irradiance on module (Chandra Mouli et al., 2016) can be divined as follows:

$$I_{glob,m} = I_{dir,m} + I_{diff,m} \quad (33)$$

The solar radiation that directly reaches the earth, is the direct radiation of the sun (Jäger et al., 2014). The direct irradiance $I_{dir,m}$ that reaches the module, is modelled as follows (Chandra Mouli et al., 2016):

$$I_{dir,m} = I_{dir} \cdot \cos(\theta_i) \quad (34)$$

With:

I_{dir} = direct normal irradiance $[W/m^2]$
$I_{dir,m}$ = direct normal irradiance on panel depending on A_m and θ_m [W/m^2]
θ_i = angel of incidence[°]

The diffuse radiation is the part that is scattered in the atmosphere (Jäger et al., 2014). A simple of isotropic model is used to model the diffuse radiation (Chandra Mouli et al., 2016):

$$I_{diff,m} = I_{diff} \cdot \frac{1 + \cos(\theta_m)}{2} \quad (35)$$

With:
I_{diff} = diffuse horizontal irradiance $[W/m^2]$

$I_{diff,m}$ = diffuse irradiance on module depending on θ_m $[W/m^2]$
θ_m = title of module[°]

The angle of incidence is the angle between the sun and the panel, which means that is depends on the position of the sun and the position of the panel (Jäger et al., 2014).

$$\theta_i \ = cos^{-1}((cos(a_s) \cdot \sin(\theta_m) \cdot \cos(A_m - A_s) \ + \sin(a_s) \cdot \cos(\theta_m)) \qquad (36)$$

There is only irradiance on the panel if the sun is above the horizon and if the angle of incidence is smaller than 90 degrees otherwise the sun is behind the panel.
Therefore, this is only valid if (Jäger et al., 2014):

$a_s \ \geq \ 0°$ and $\theta_i \ \leq \ 90°$

Shading

The distance that is needed between two row is calculated to avoid shadow casting of panels on other panels (Jäger et al., 2014).
Length shadow:

$$d = L*(\cos(\theta_m) + \sin(\theta_m)*\cot(\alpha_s)*\cos(A_m - A_s) \quad (37)$$

The distance is computed for the shortest day of the year, which is 21th of December. It is calculated to prevent shadowing from 10:00-15:00 in Rotterdam. The sun is lower at 15:00 than at 10:00, with an altitude 8.6 degrees. This would mean that the panels should have a distance of 5.6 meters.

The rule of thumb which is 3 times the length, gives a distance of 4.8 meters.
The panel with the largest tilt in this case study is 37 degrees and has an orientation of 165 degrees (almost south). The difference between 5.6 meters and 4.8 meters distance between the rows, results in 744 hours and 1172 hours shading respectively.
It has been noticed that on most of the days two hours of shading are casted due to the large shadows when the sun is rising or setting.
The panels that have a smaller tilt, cast significant less hours of shading. In this research it is chosen to use the rule of thumb of three times the length of the module. Insufficiently information is available about the roof. Since only 45% of the roof can be used, most probably the rows can be placed with some more distance between each other. If the distance of 5.6 meters would be used to avoid mutual shading, this could lead to an underestimation of the possible energy that could be produced. For example, only one row could be placed while before two rows could be installed. When having more detailed information available about the roof, the system can be optimized according the landscape of the roof.
The shadow casted by the surrounded buildings on the roof decreases the energy performance of the solar panels.

$$P_{prod,sys} = ((1 - (f_{shadow\ build}(t)) * (I_{glob}(t)) \quad (38)$$

$P_{prod,sys}$ = power product solar panel system
$f_{shadow\ build}$ = shadow factor; shadow casted on roof from surrounded buildings

Pumping station

Pumping water through the sewage system requires energy. The amount of water that needs to be pumped away depends on: the amount of paved surface or the number of households. Energy could be saved by reducing the amount of water that needs to be pumped through the sewage system. This could be achieved by uncoupling the rainwater falling on the roofs of the building from the sewage system. The rainwater will finally flow into the ground water. The pumps that keep the ground water at the right water level require significant less energy.

An average sewage district including one main pumping station in Rotterdam, has a size of about 100 hectares urban area. The area of the neighbourhood in the case study is about 37,200 m2 which is less than 4%. It is hard to estimate the possible energy reduction that could be achieved in such a small area (Van der Linden, L., personal communication, December 2016). In contrary, if such a measure would be applied to a whole sewage district (of around 100 hectares), a more accurate estimation of the energy reduction can be made. For example, this can make it possible to install a different pump leading to significant energy reduction.

To get an indication of possible energy reduction in the case study neighbourhood, the following could be calculated:
Rainfall yearly average in Rotterdam = 800 mm
Rainfall in sewage system (after evaporation and infiltration) = 600 mm
Factor that does not end up in sewage system due to overflow = 0.05
Rainfall ending in sewage system is 570 mm

The roofs of the neighbourhood are about 6904 m2, resulting in 3935 m3 water per year that could be conserved for not flowing into the sewage system. The average energy consumption of the pumping stations in Rotterdam is 0.2 kWh/m3 (Kemeling, A., personal communication, December 2016). This is the energy that is needed to pump the water volume to a water treatment. In the case study neighbourhood, disconnecting the rainwater from the roofs results in a total electricity reduction of 787 kWh/year.
This outcome is very small compared to other energy loads in the neighbourhood. Therefore, the energy consumption and the possible reduction of the pumping stations will no longer included in this research
This calculation gives an order of indication. A more accurate evaluation can be made if the area under investigation is larger. Then it becomes possible to determine the impact on a pumping station. Nevertheless, the overall impact of pumping stations with respect to the overall energy use will remain very small. Optimizing the energy consumption of pumping stations are therefore seen as a secondary target in the total energy profile of an urban area
Information about pumping stations with input from:
(Van der Linden, L., personal communication, December 2016)
(Kemeling, A., personal communication, December 2016)
(De Voogt, K., personal communication, December 2016)
(Vermeulen, K., personal communication, December 2016)

Street lights

Type of lamp current situation	Number of lamps in case study	Power per lamp including system (watt)	Replacement with LED lamps	Power per lamp including system (watt)	Power per lamp at 50% dimming (watt)
PLL 36W KL.830 XTRA POLAR	12	38	LUXIS2000	22	11
CPO-TW 60W KL.728	50	63	LUMA 6000	52	26
Total	62				

Table 41 Street lights present in the case study

Heated volume

The length and width are taken from the dataset BAG panden (Gemeente Rotterdam, 2016). The height is schematized as 3 meters per floor. The basements of the flats are modelled as 1 meter height, these are half underground.
The row houses have a gable roof. About one third of the buildings adjusted the attic with a dormer window and these buildings use the attic as a living space.

The area of the row houses is 115 m2. The gable roof is modelled as a floor with half the height. In this way the volume is similar.

The following table shows the dimensions of the building and the dimensions that are used to model the heat balance. The table shows that especially the flats have a big difference in the total volume and the modelled heated area. This could have a significant influence on the model.

		Units	Flat type 1	Flat type 2	Flat type 3	Row houses
Dimension apartment	Average area apartment	m2	68	66	66	115
Dimensions whole building	Height	m	19	13	13	9
	Length	m	151	88	65	36
	Width	m	11.5	11	10.5	8
	Volume	m3	32,994	12,584	8,873	2,664
Dimensions heated part building	Height	m	18	12	12	7.5
	Length	m	146	80	56	36
	Width	m	9.5	9	9.5	8
	Volume	m3	24,966	9,504	8,640	2,220

Table 42 Dimensions per case study

In comparison to the internship report (Hofgärtner, 2016), some numbers are adjusted because new documents became available that were more precise

D. Additional graphs

General

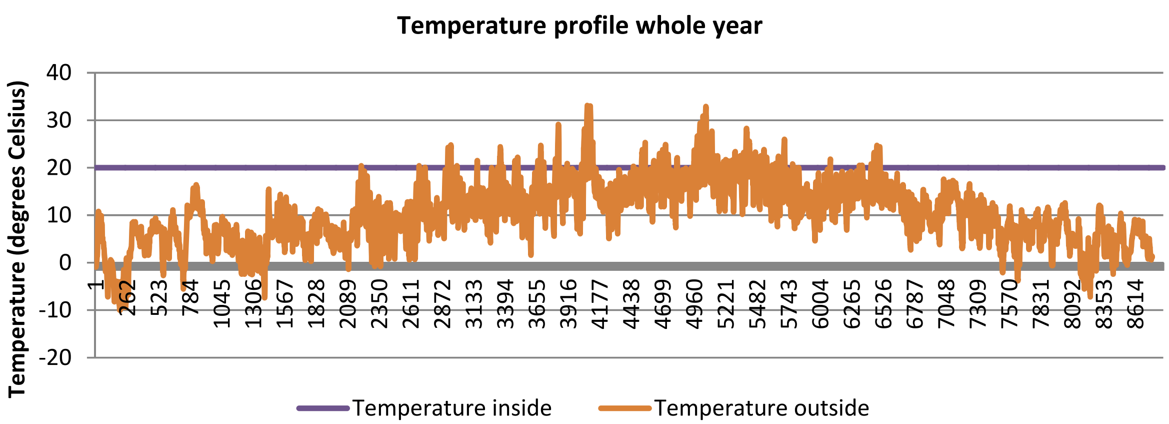

Table 43 Temperature

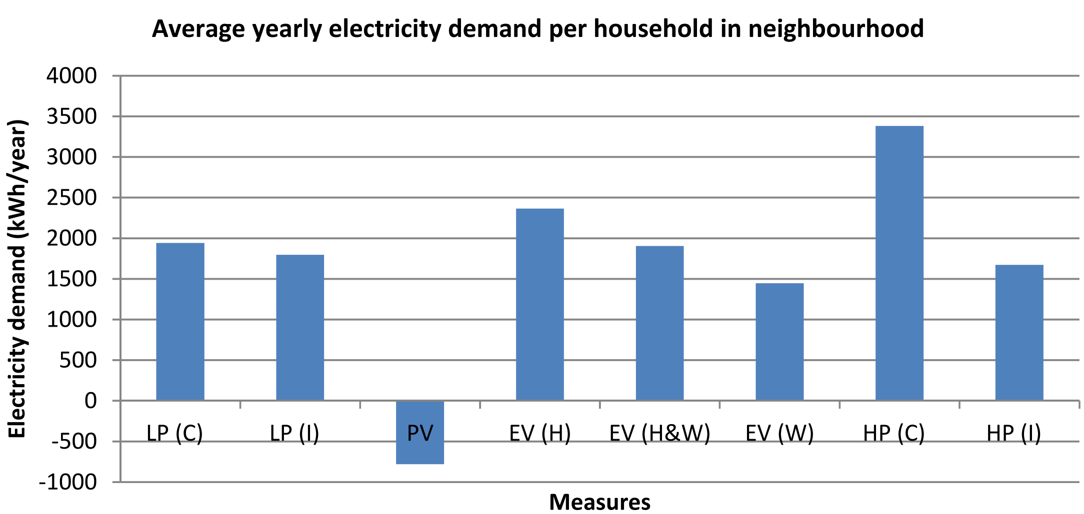

Figure 104 Electricity demand per measure

Electricity

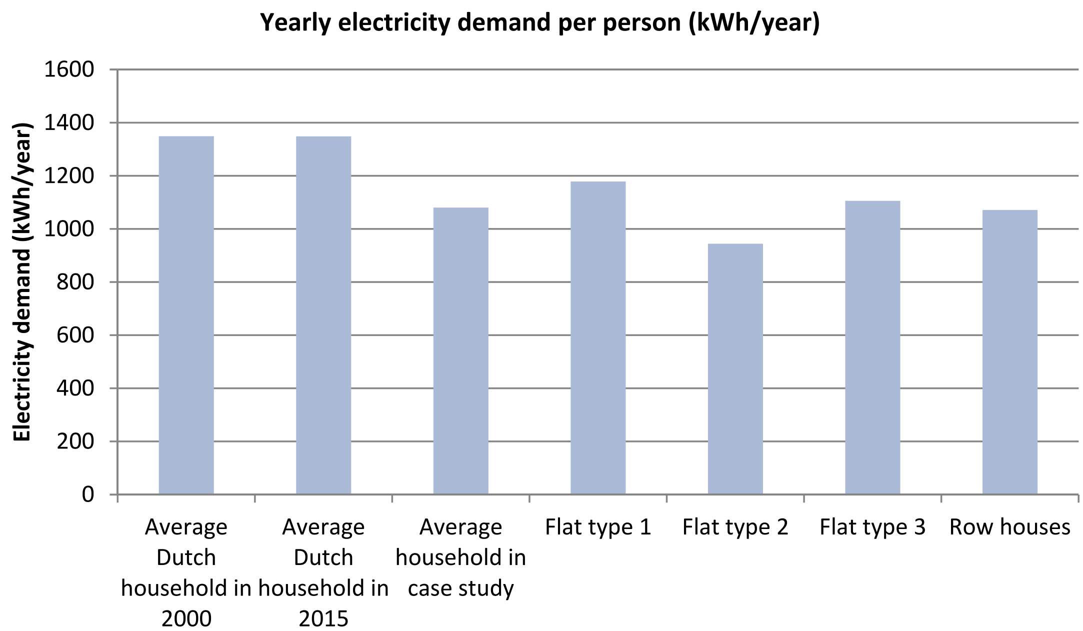

Figure 105 Yearly electricity demand per person (kWh/year)

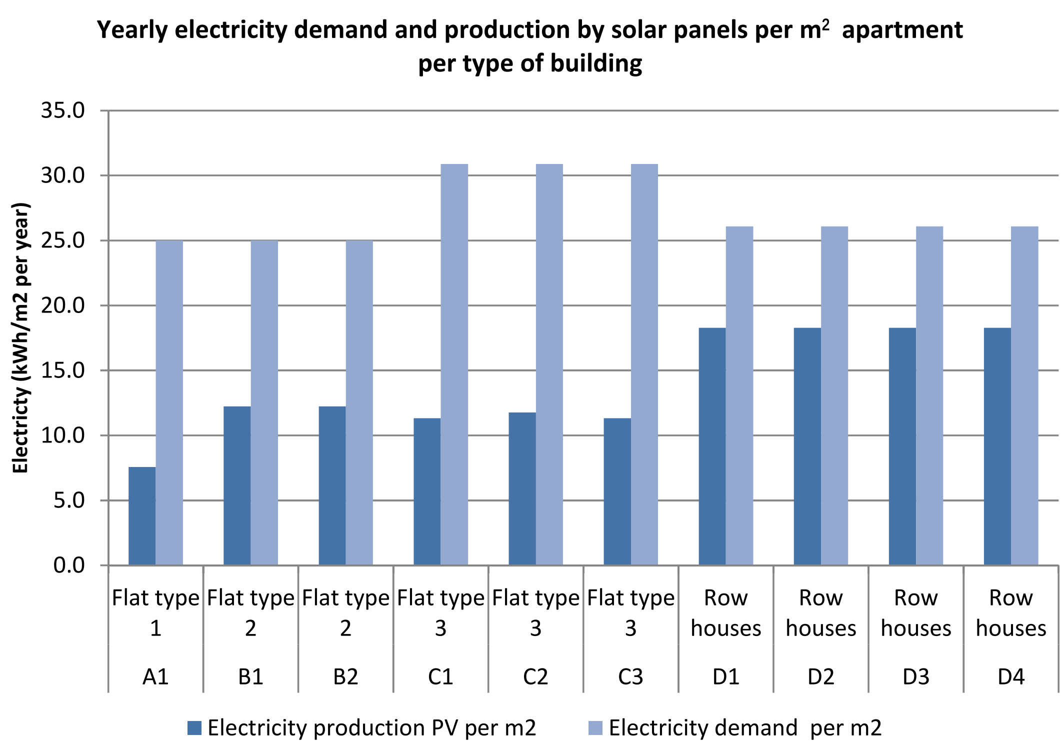

Figure 106 Yearly electricity demand and production by solar panels per m² apartment

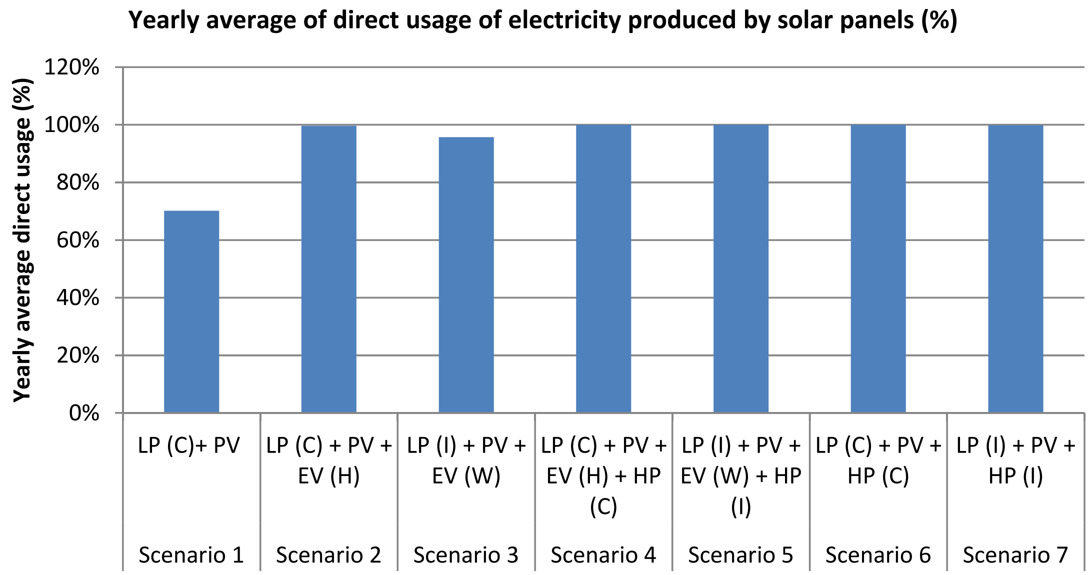

Figure 107 Direct usage of electricity produced by solar panels

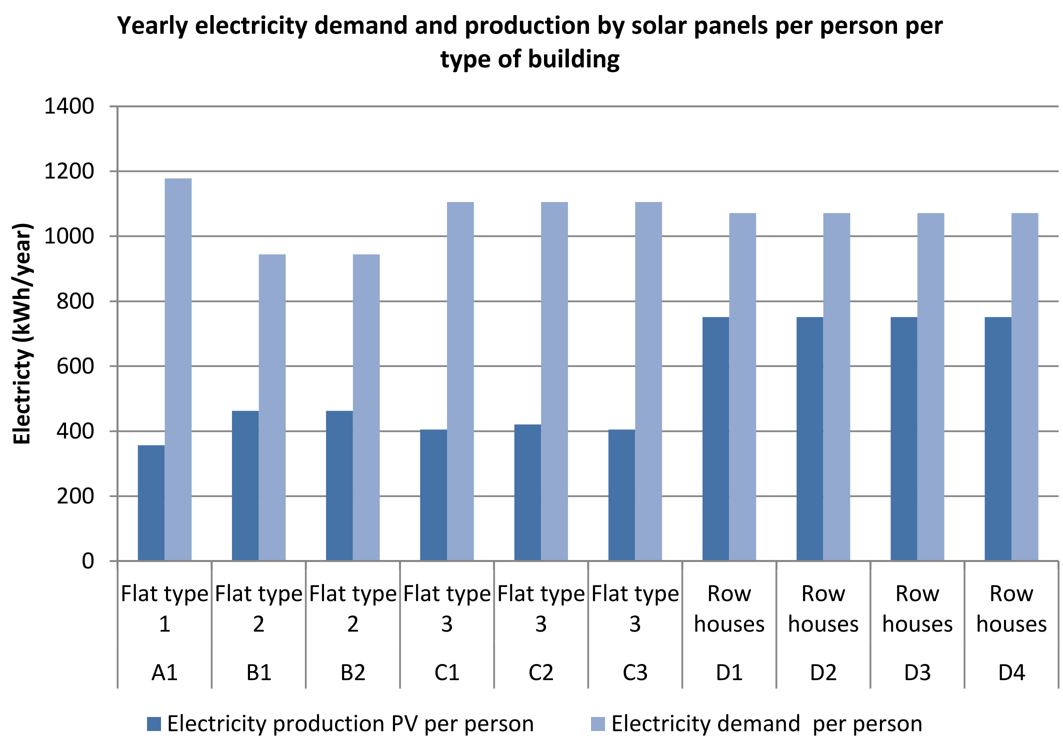

Figure 108 Yearly electricity demand and production by solar panels per person per type of building

Heating

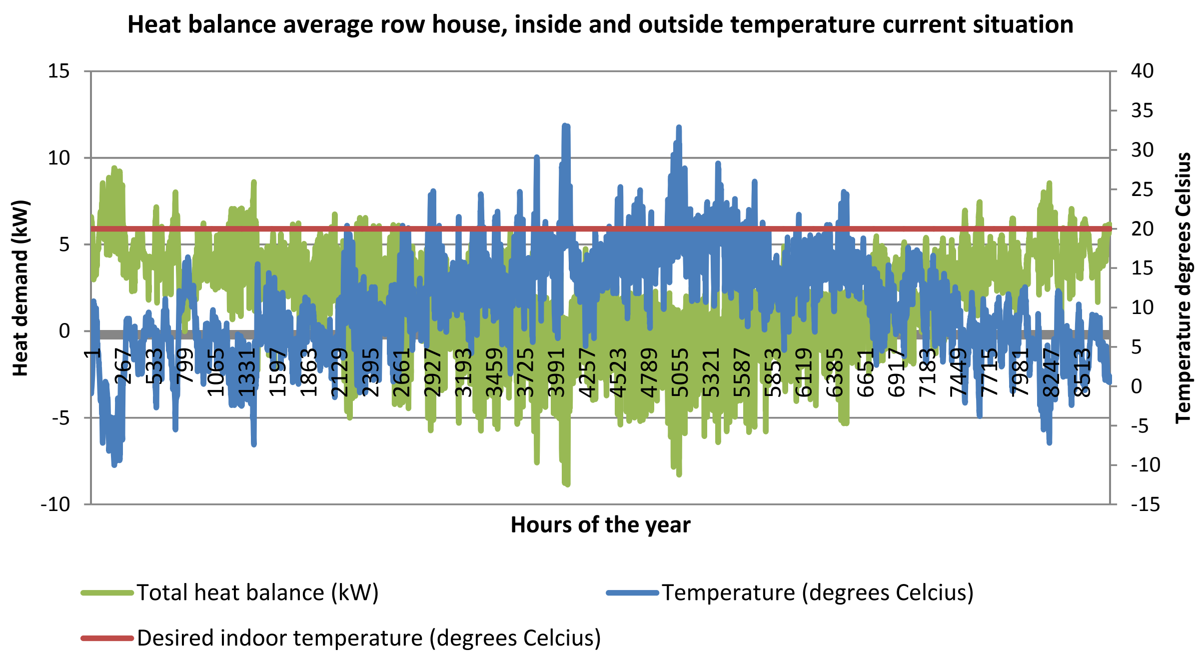

Figure 109 Heat balance average row house, inside and outside temperature current situation

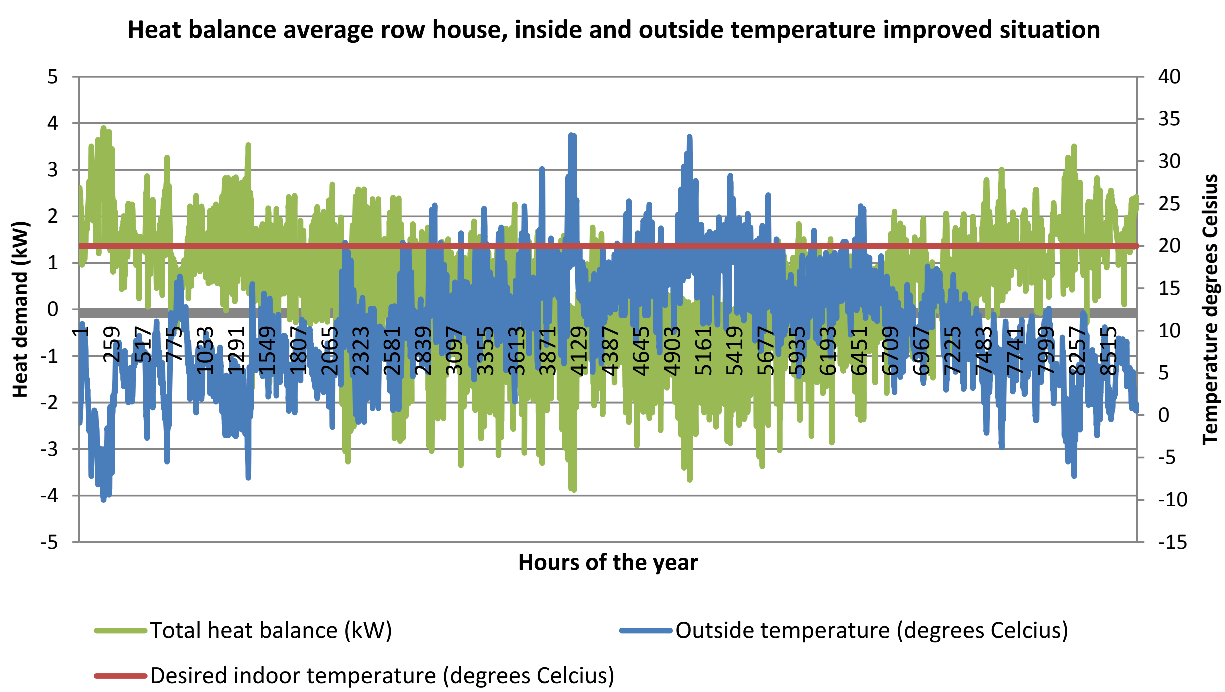

Figure 110 Heat balance average row house, inside and outside temperature improved situation

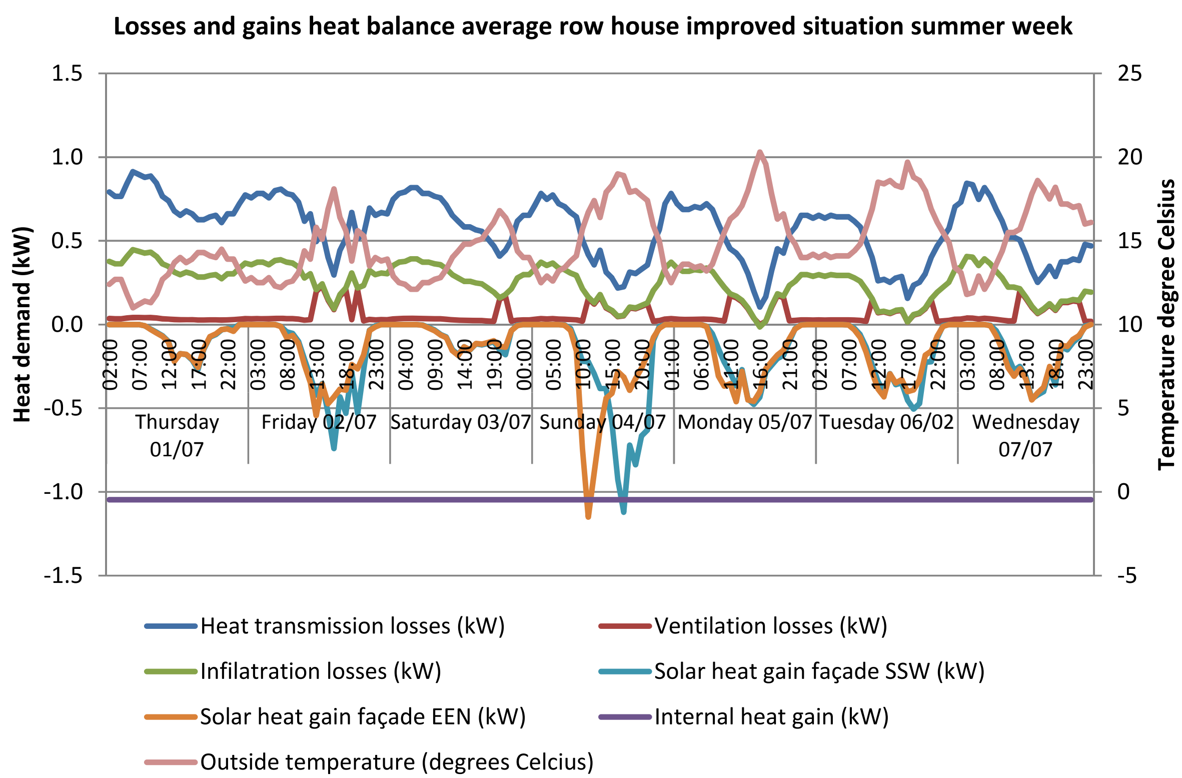

Figure 111 Losses and gains heat balance average row house improved situation summer week

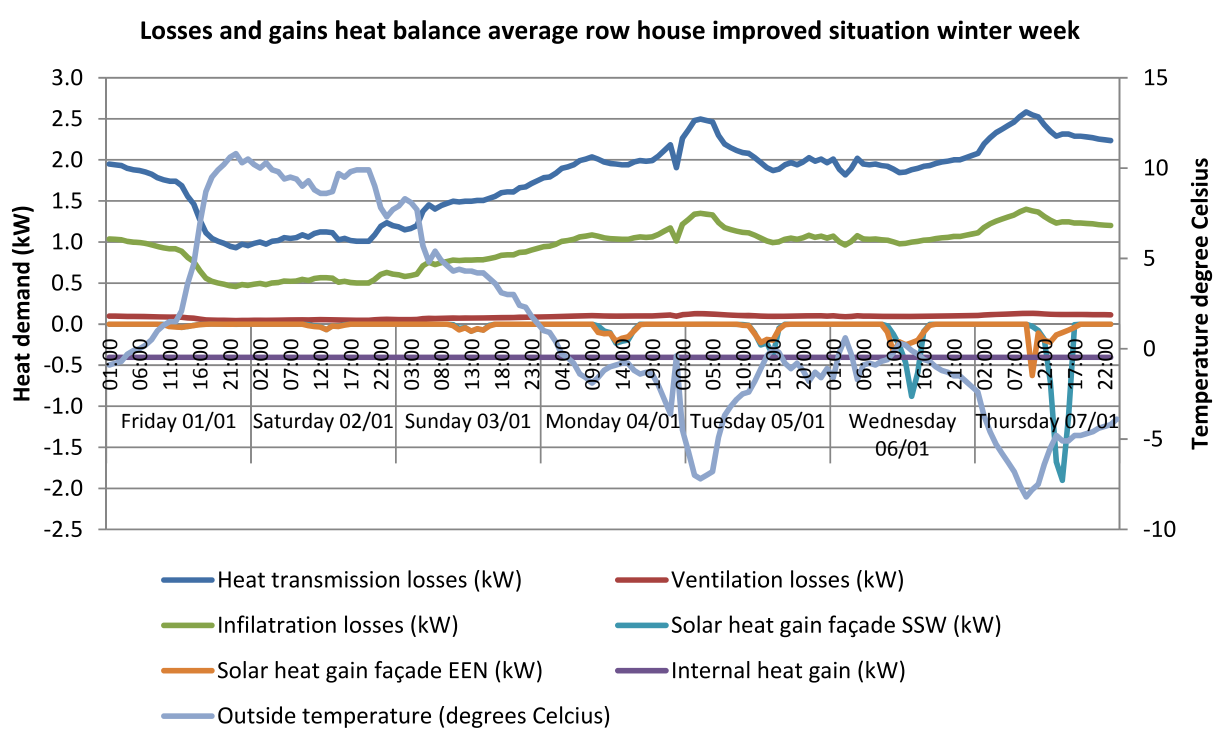

Figure 112 Losses and gains heat balance average row house improved situation winter week

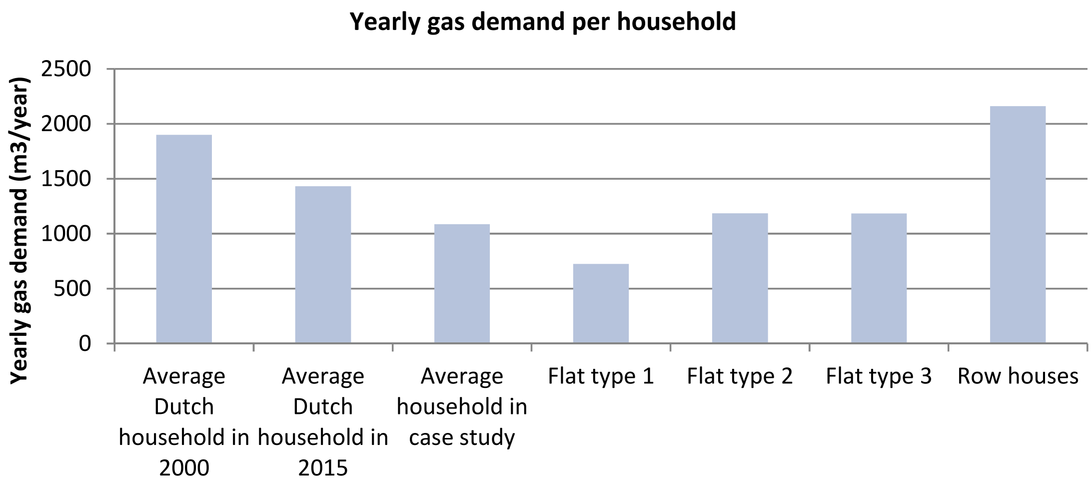

Figure 113 Yearly gas demand per household

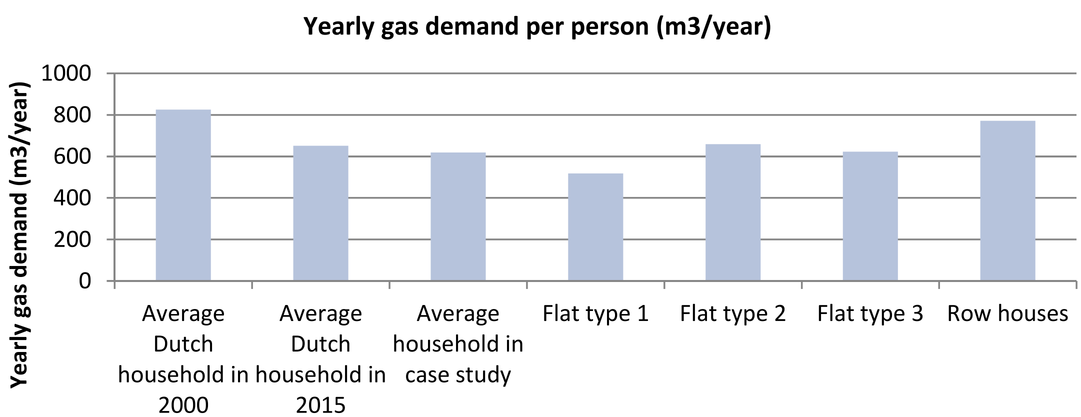

Figure 114 Yearly gas demand per person

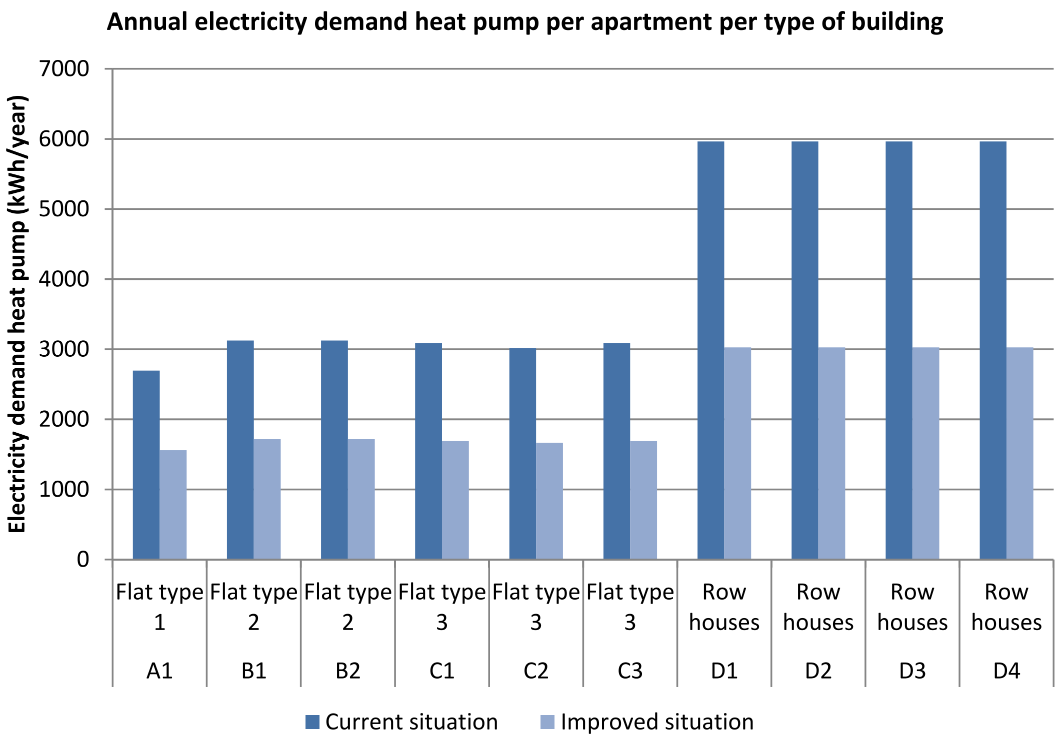

Figure 115 Annual electricity demand heat pump per apartment per type of building

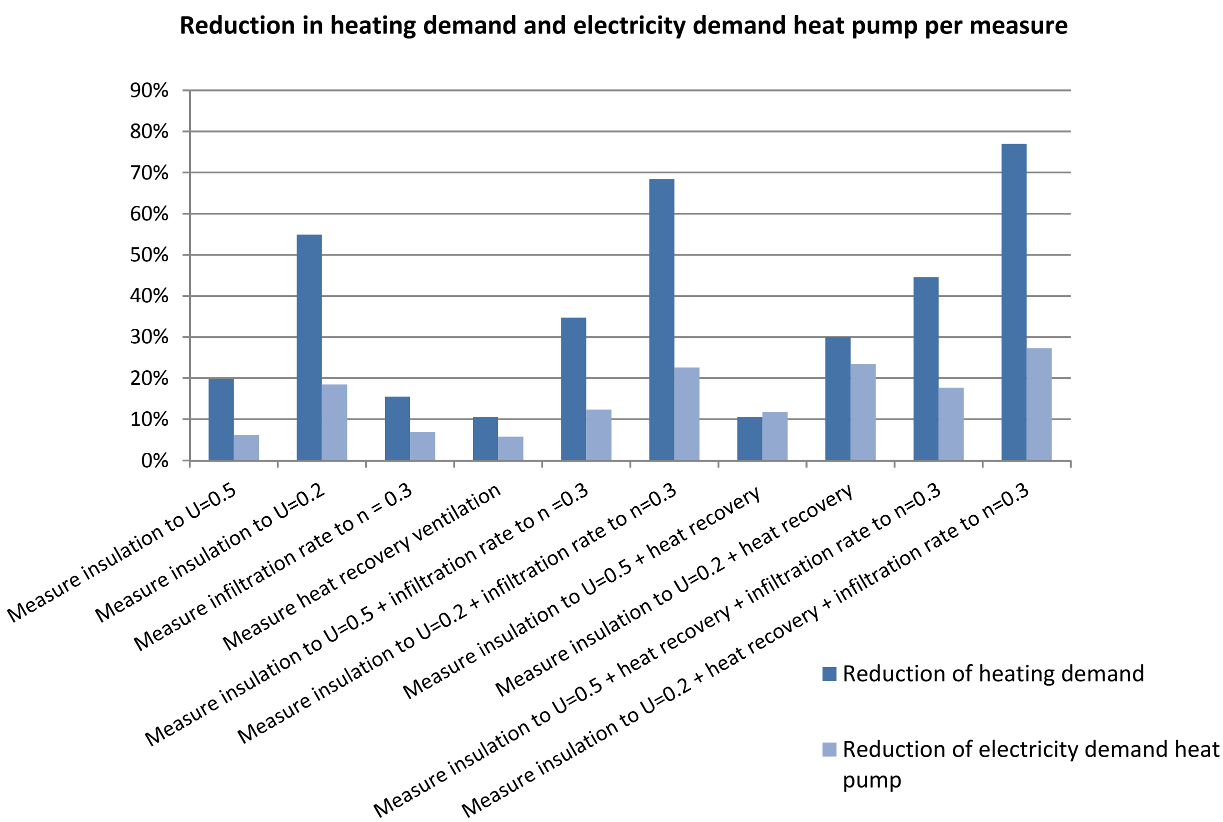

Figure 116 Reduction in heating demand and electricity demand heat pump

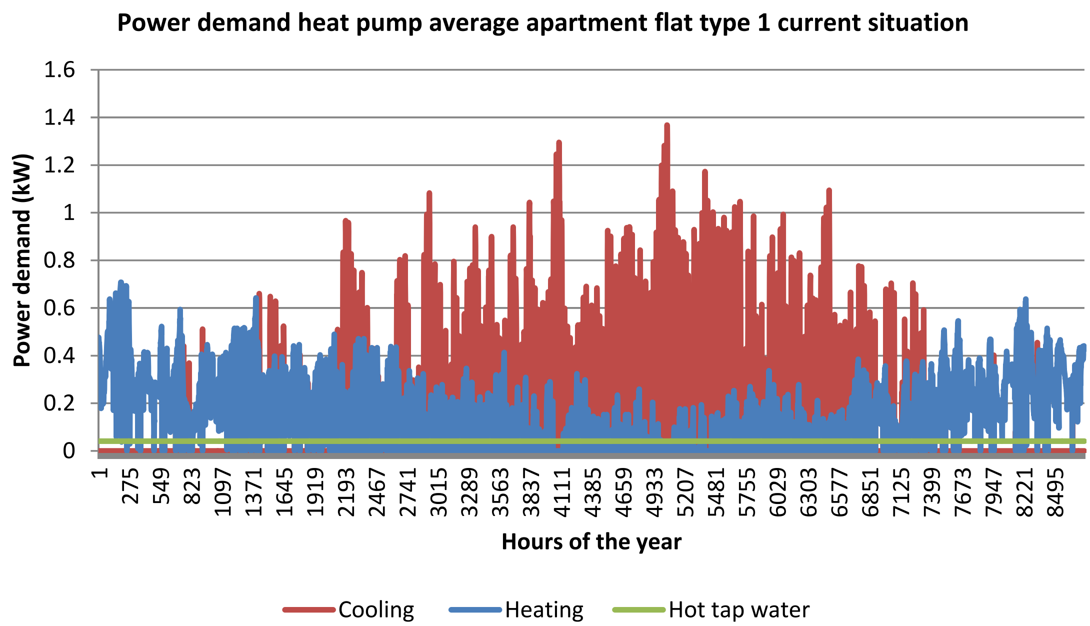

Figure 117 Power demand heat pump average apartment flat type 1 current situation

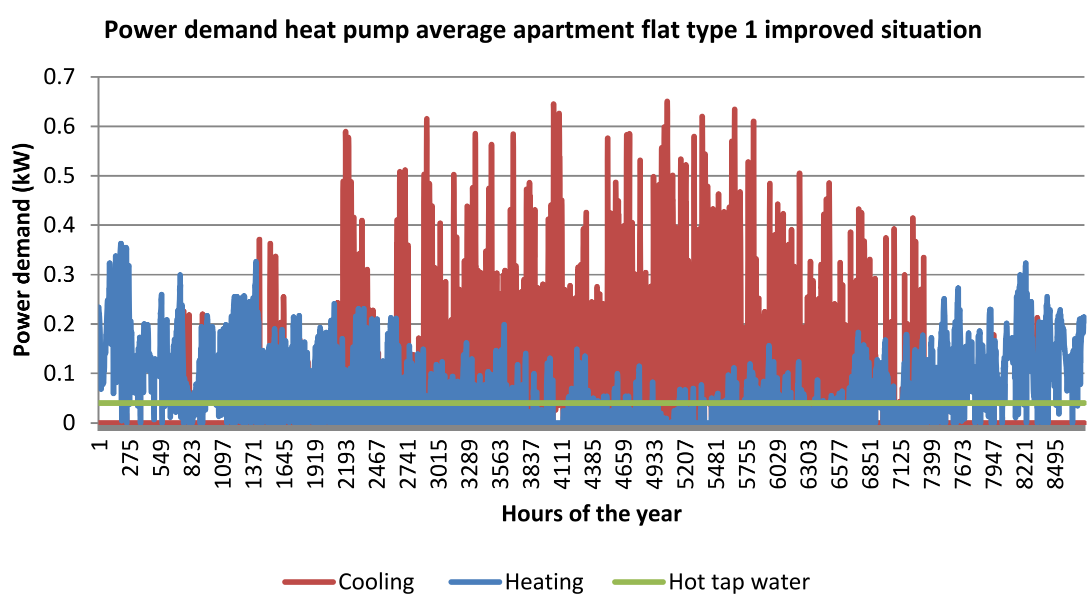

Figure 118 Power demand heat pump average apartment flat type 1 improved situation

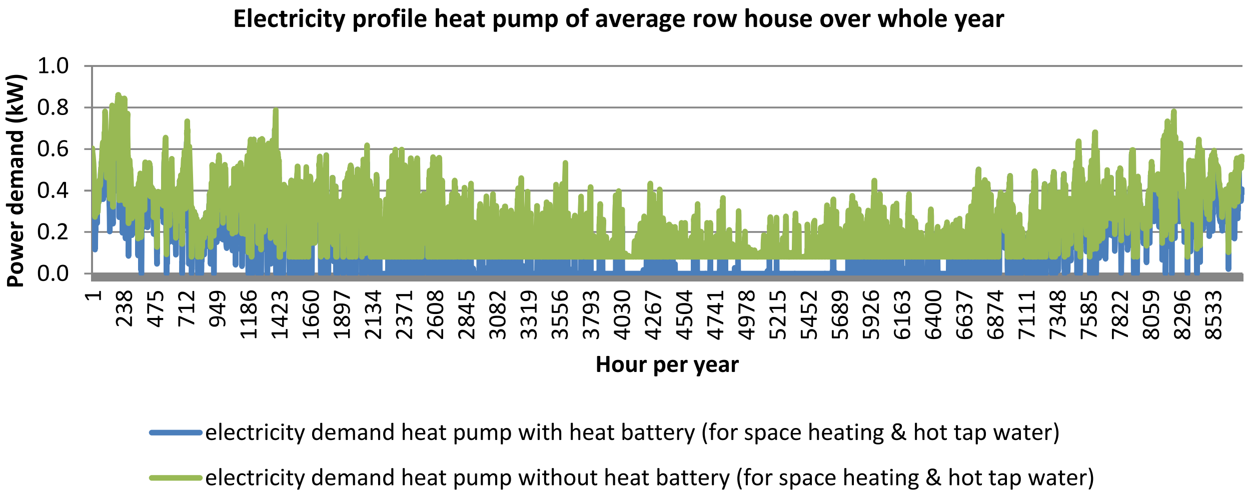

Figure 119 Electricity profile heat pump of average row house over whole year

Measures on building level

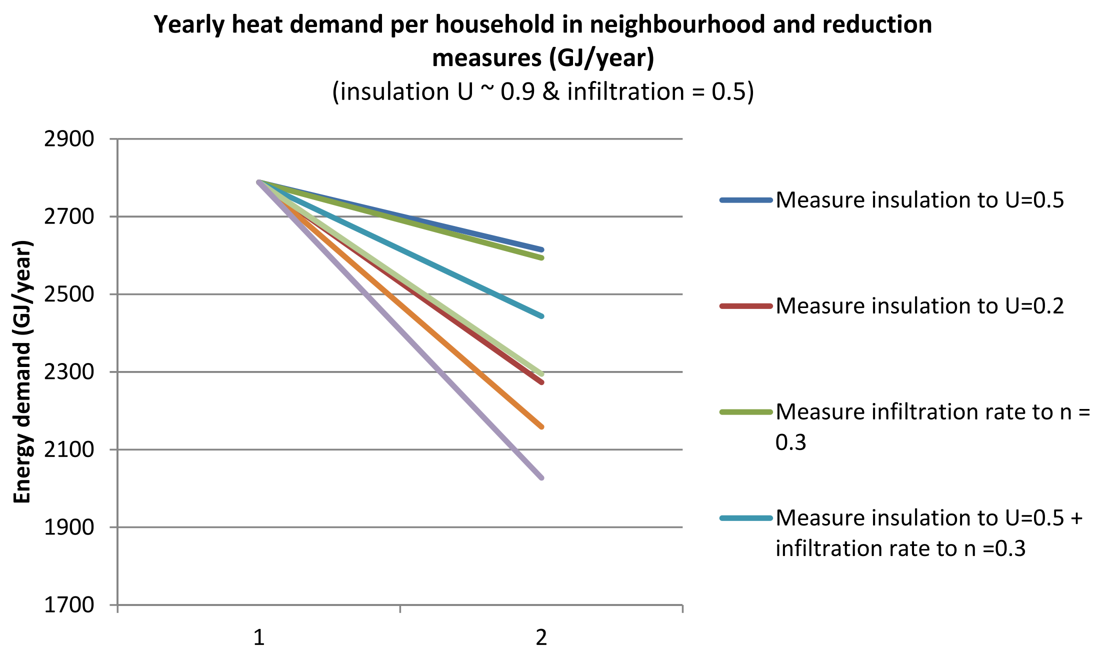

Figure 121 Yearly heat demand per household in neighbourhood and reduction measures (GJ/year)

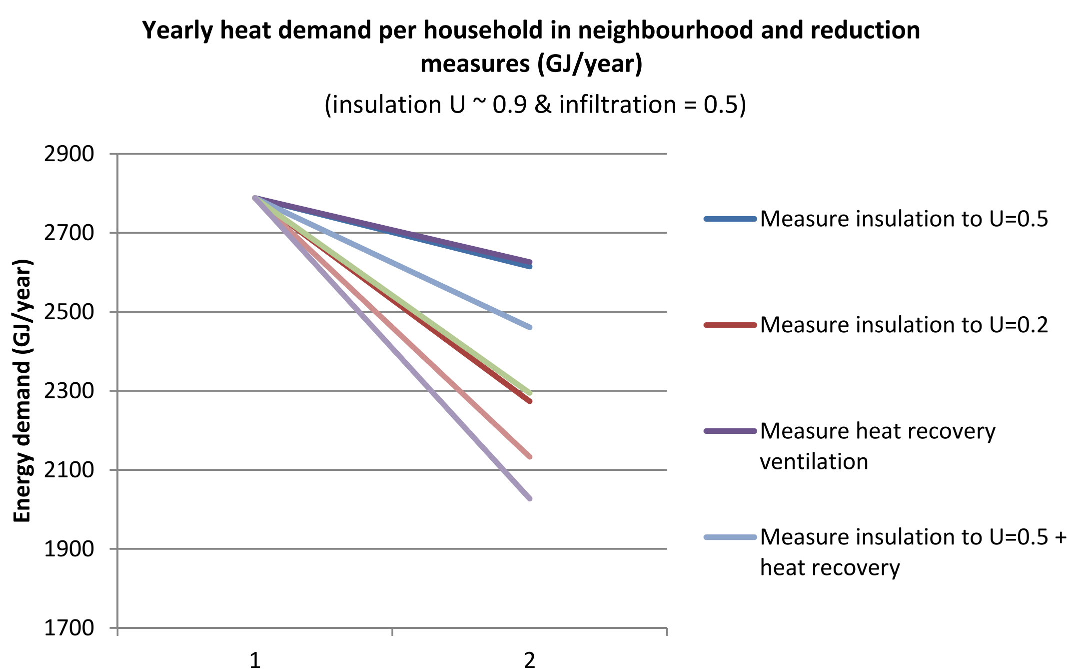

Figure 122 Yearly heat demand per household in neighbourhood and reduction measures (GJ/year

Electricity demand profiles measures

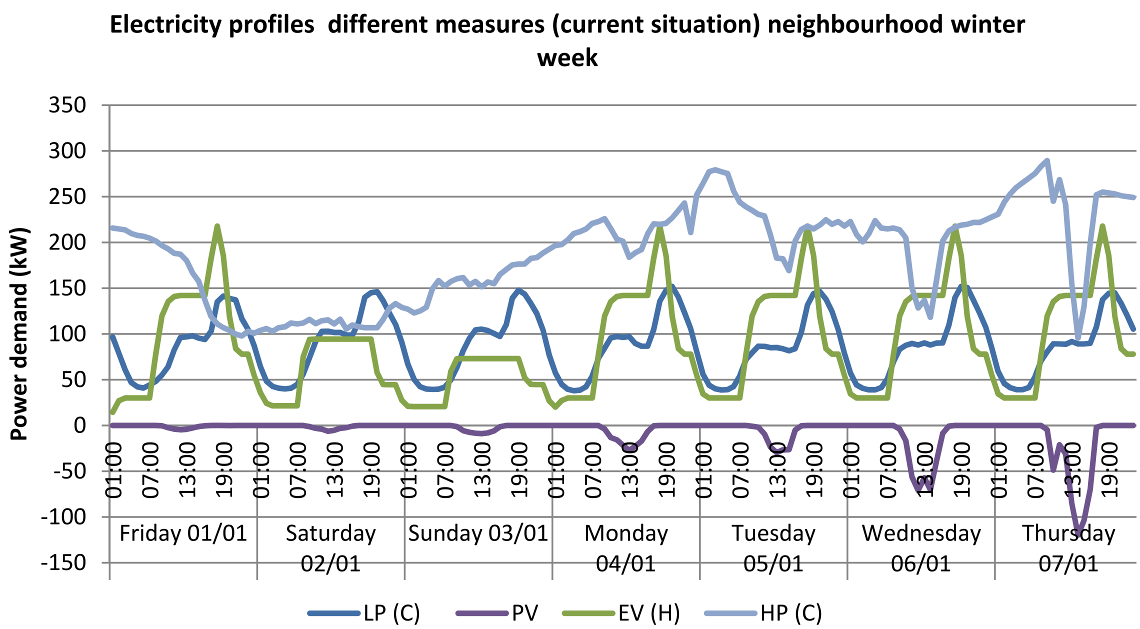

Figure 123 Electricity profiles different measures (current situation) neighbourhood winter week

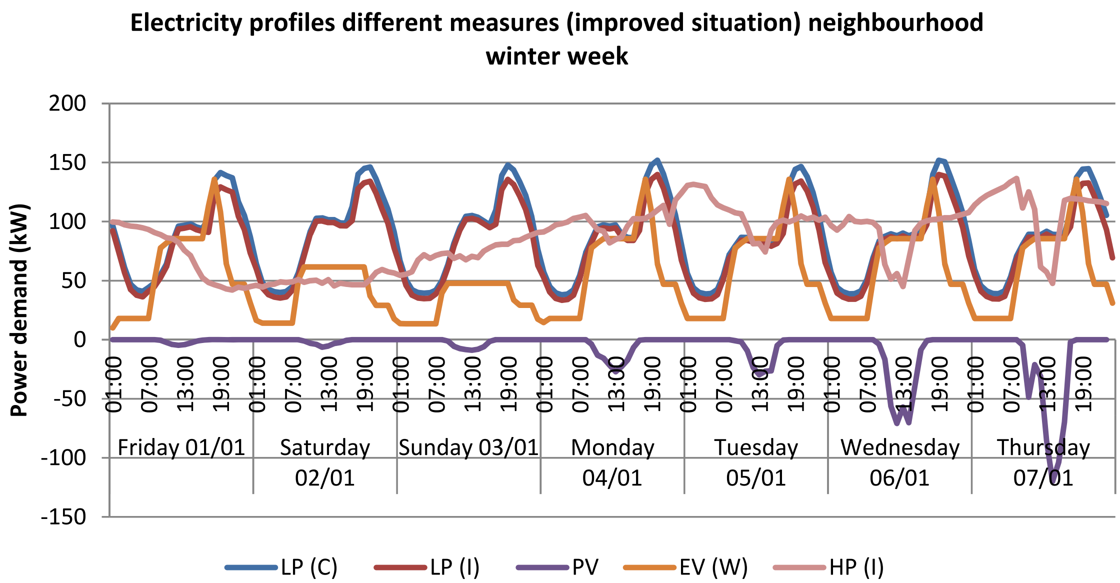

Figure 124 Electricity profiles different measures (improved situation) neighbourhood winter week

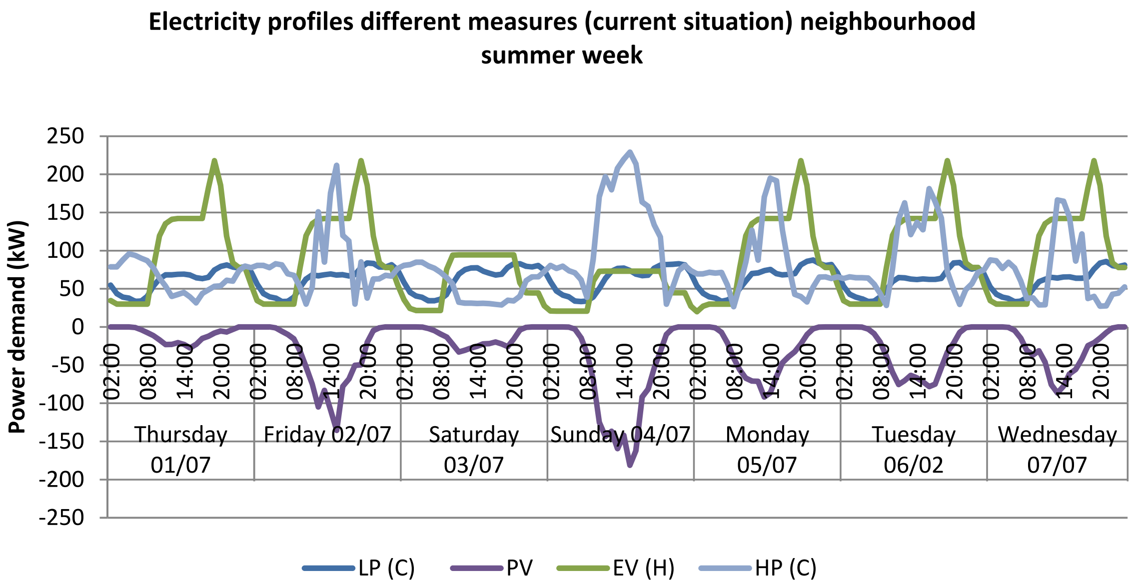

Figure 125 Electricity profiles different measures (current situation) neighbourhood summer week

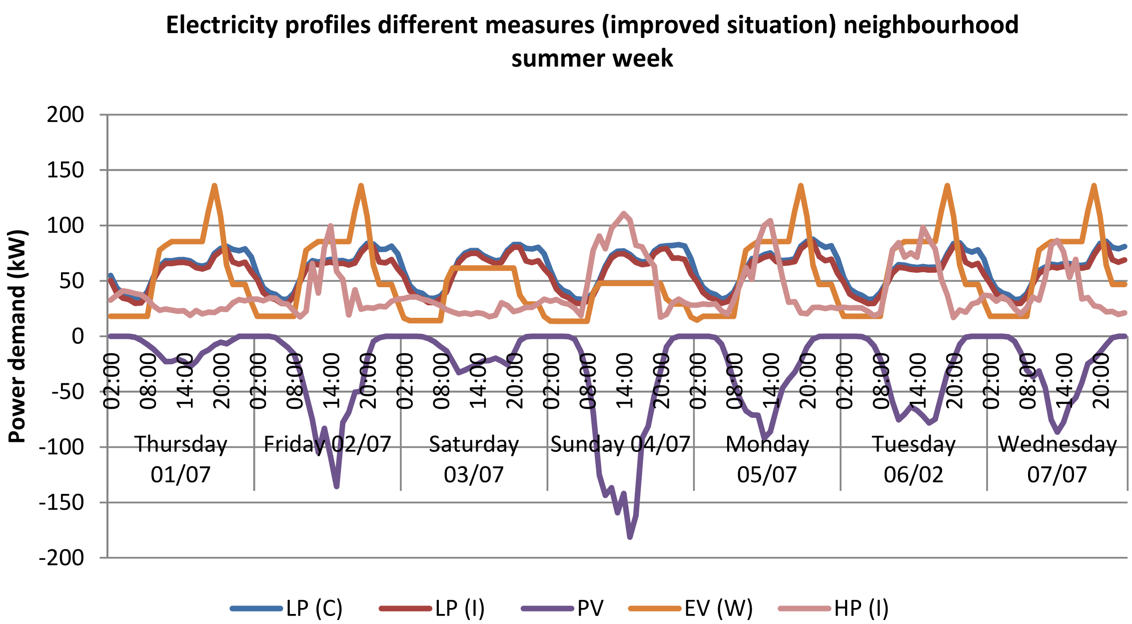

Figure 126 Electricity profiles different measures (improved situation) neighbourhood summer week

Single scenarios

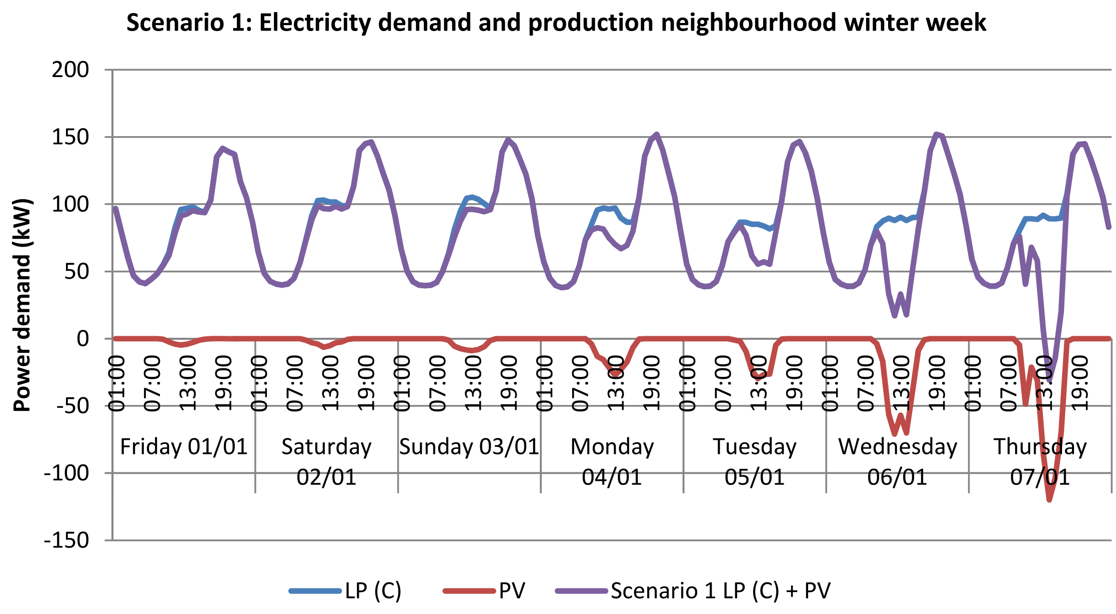

Figure 127 Scenario 1: Electricity demand and production neighbourhood winter week

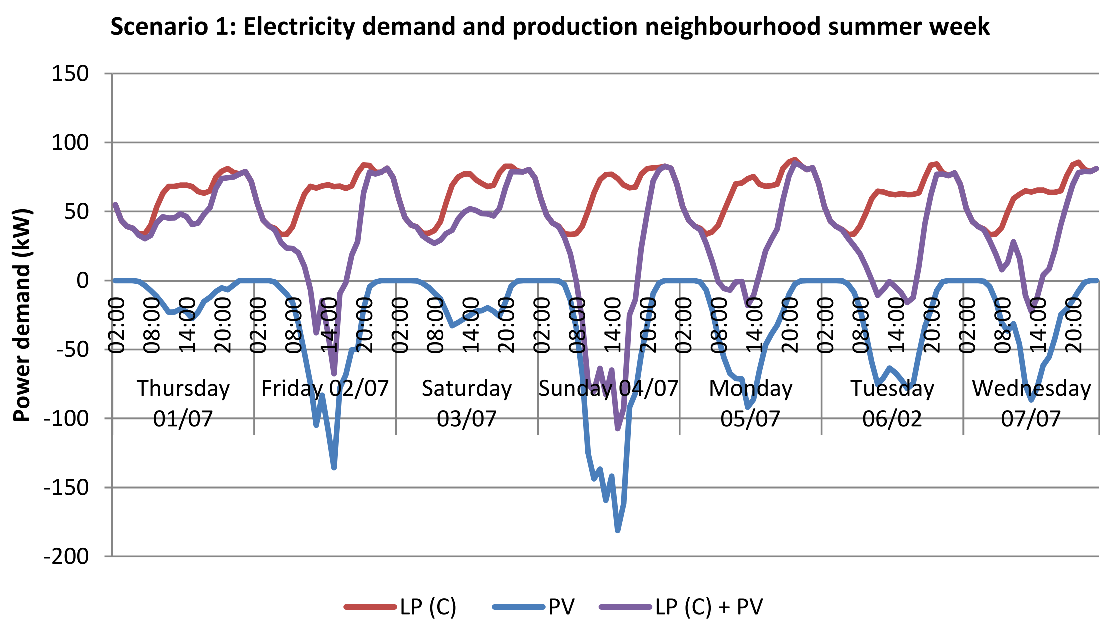

Figure 128 Scenario 1: Electricity demand and production neighbourhood summer week

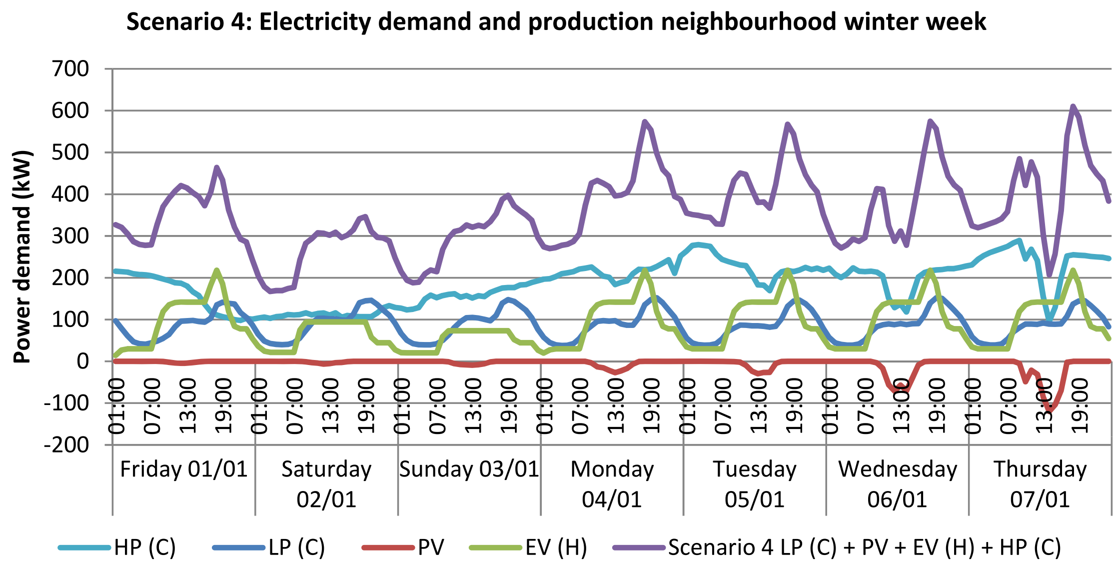

Figure 129 Scenario 4: Electricity demand and production neighbourhood winter week

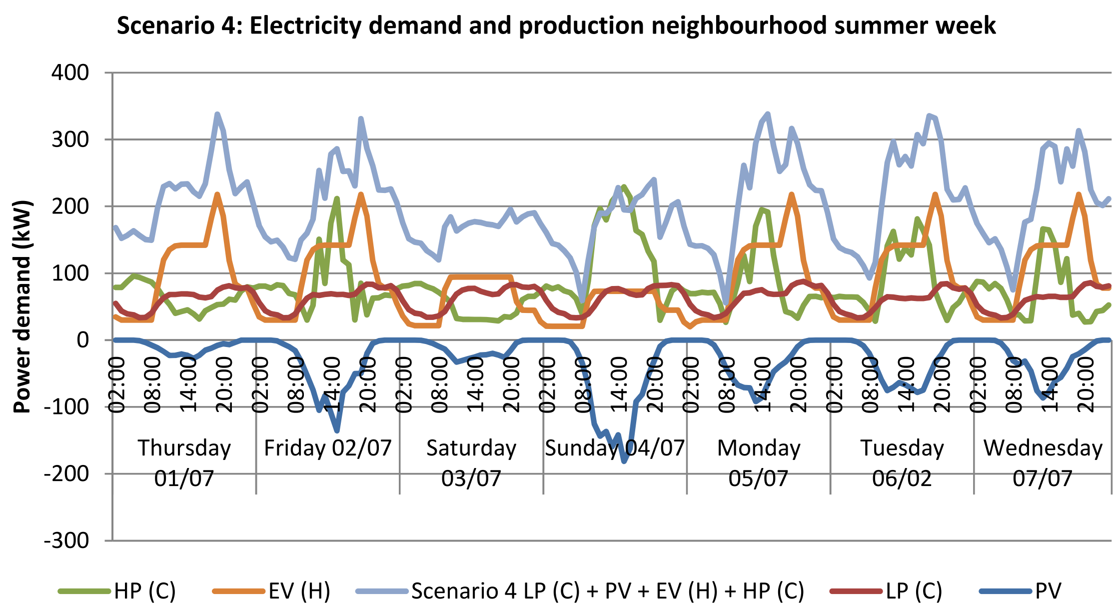

Figure 130 Scenario 4: Electricity demand and production neighbourhood summer week

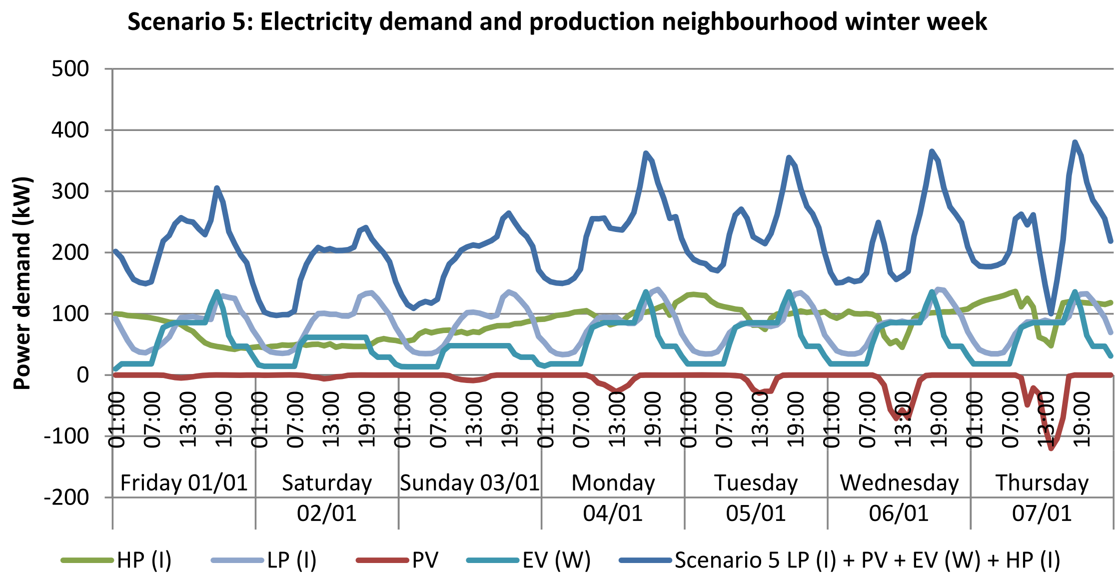

Figure 131 Scenario 5: Electricity demand and production neighbourhood winter week

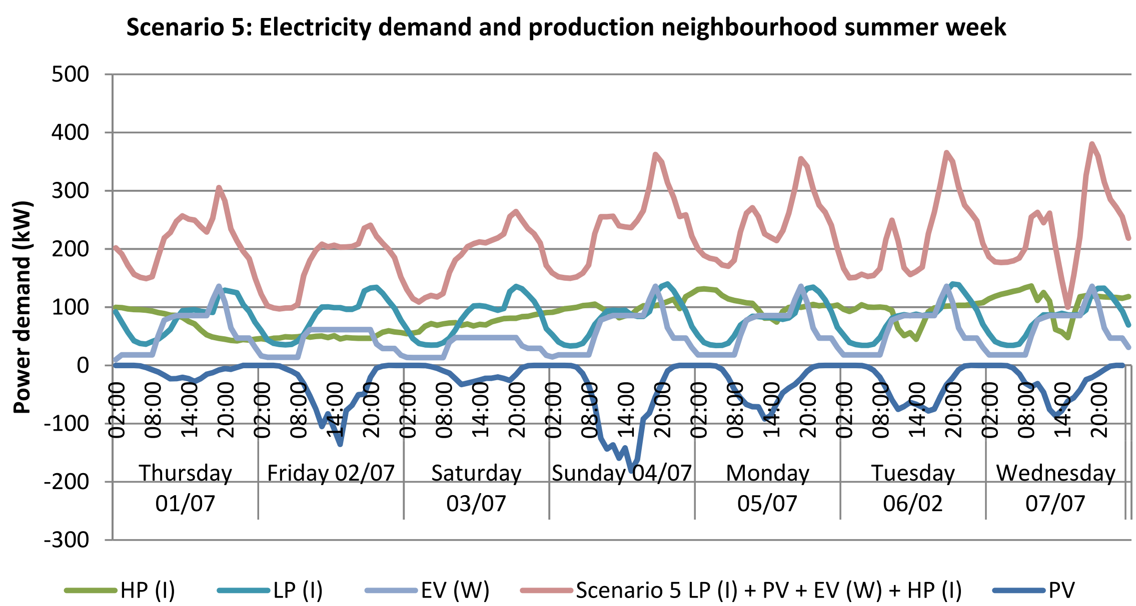

Figure 132 Scenario 5: Electricity demand and production neighbourhood summer week

Combined scenarios

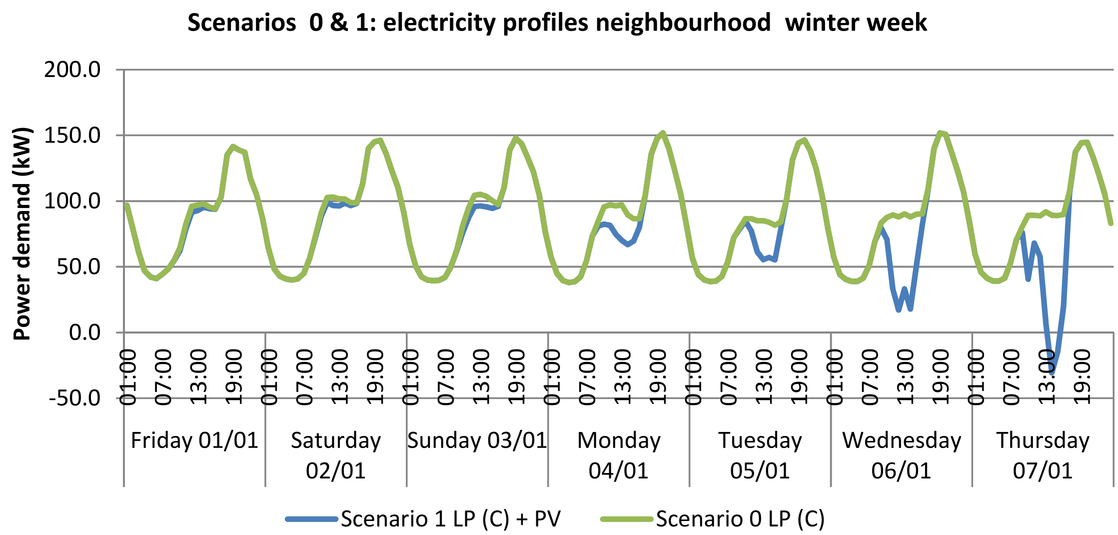

Figure 133 Scenarios 0 & 1: electricity profiles neighbourhood winter week

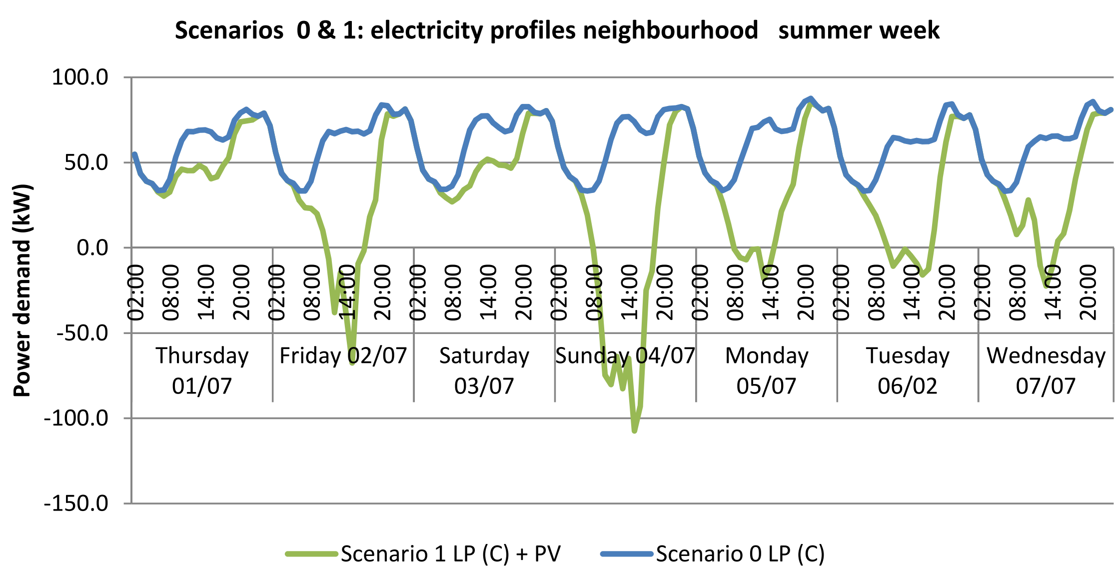

Figure 134 Scenarios 0 & 1: electricity profiles neighbourhood summer week

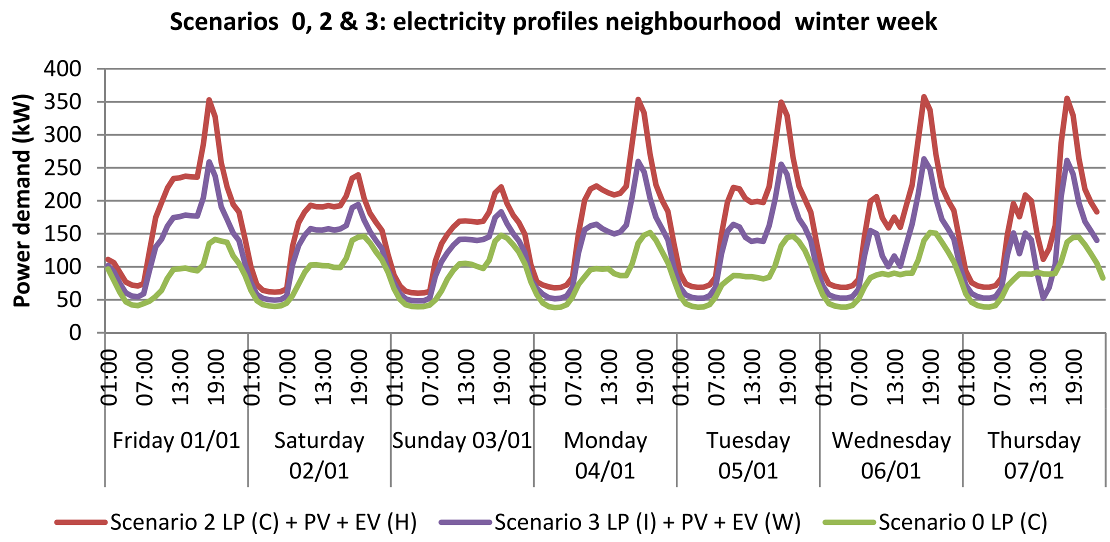

Figure 135 Scenarios 0, 2 & 3: electricity profiles neighbourhood winter week

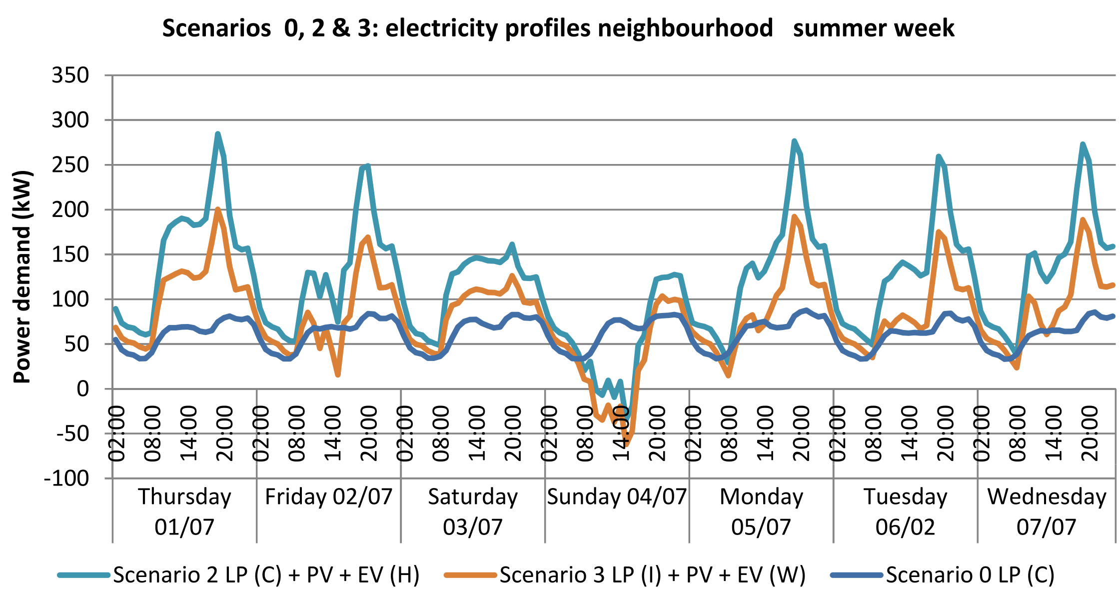

Figure 136 Scenarios 0, 2 & 3: electricity profiles neighbourhood summer week

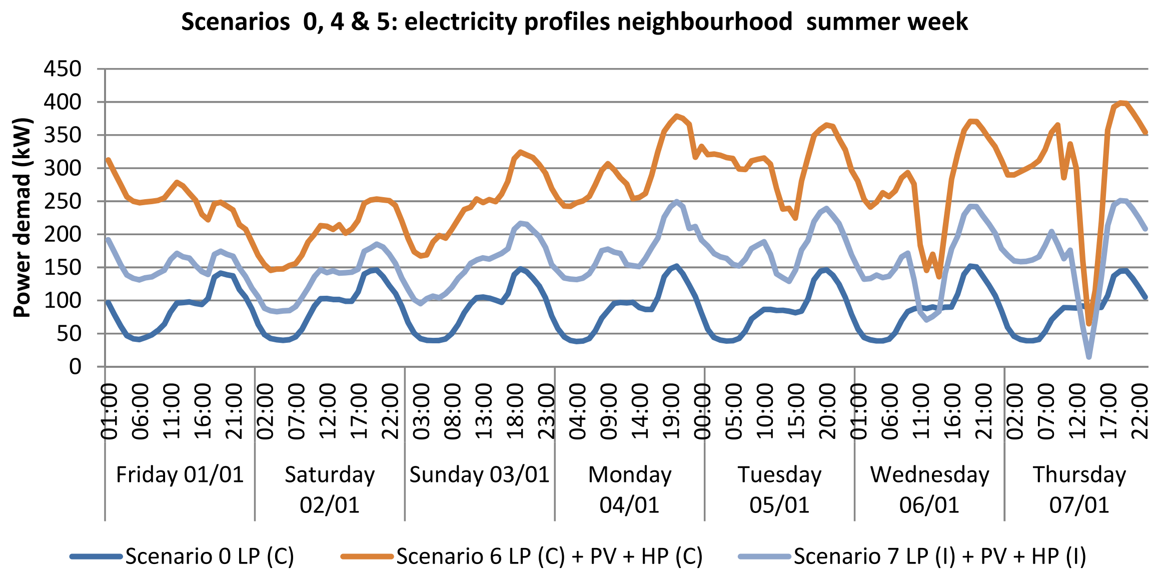

Figure 137 Scenarios 0, 4 & 5: electricity profiles neighbourhood summer week

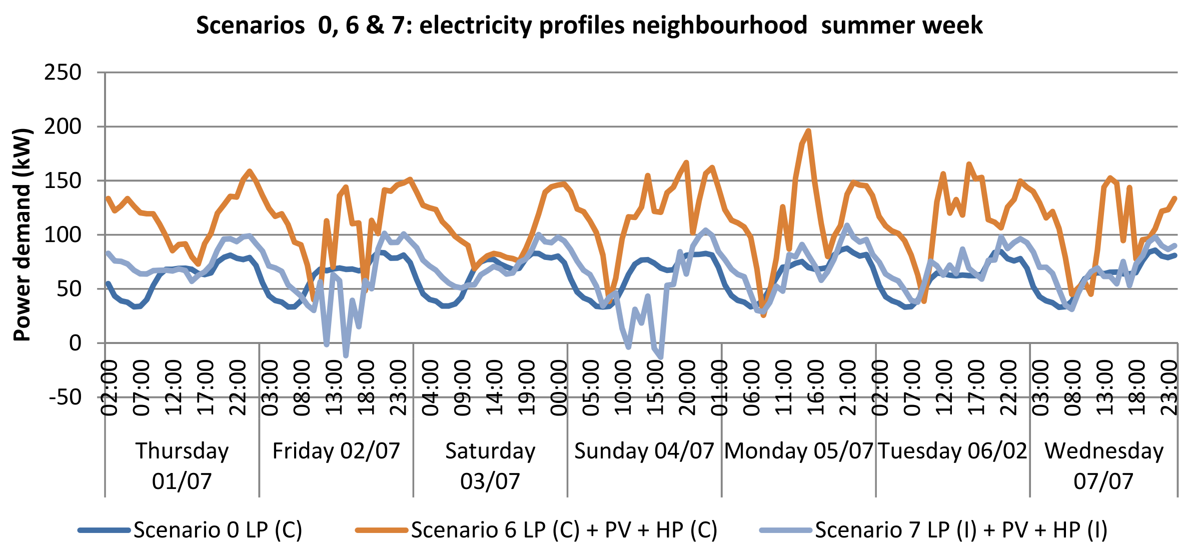

Figure 138 Scenarios 0, 6 & 7: electricity profiles neighbourhood summer week