Residential Energy Transition

of Amsterdam Nieuw West neighbourhoods

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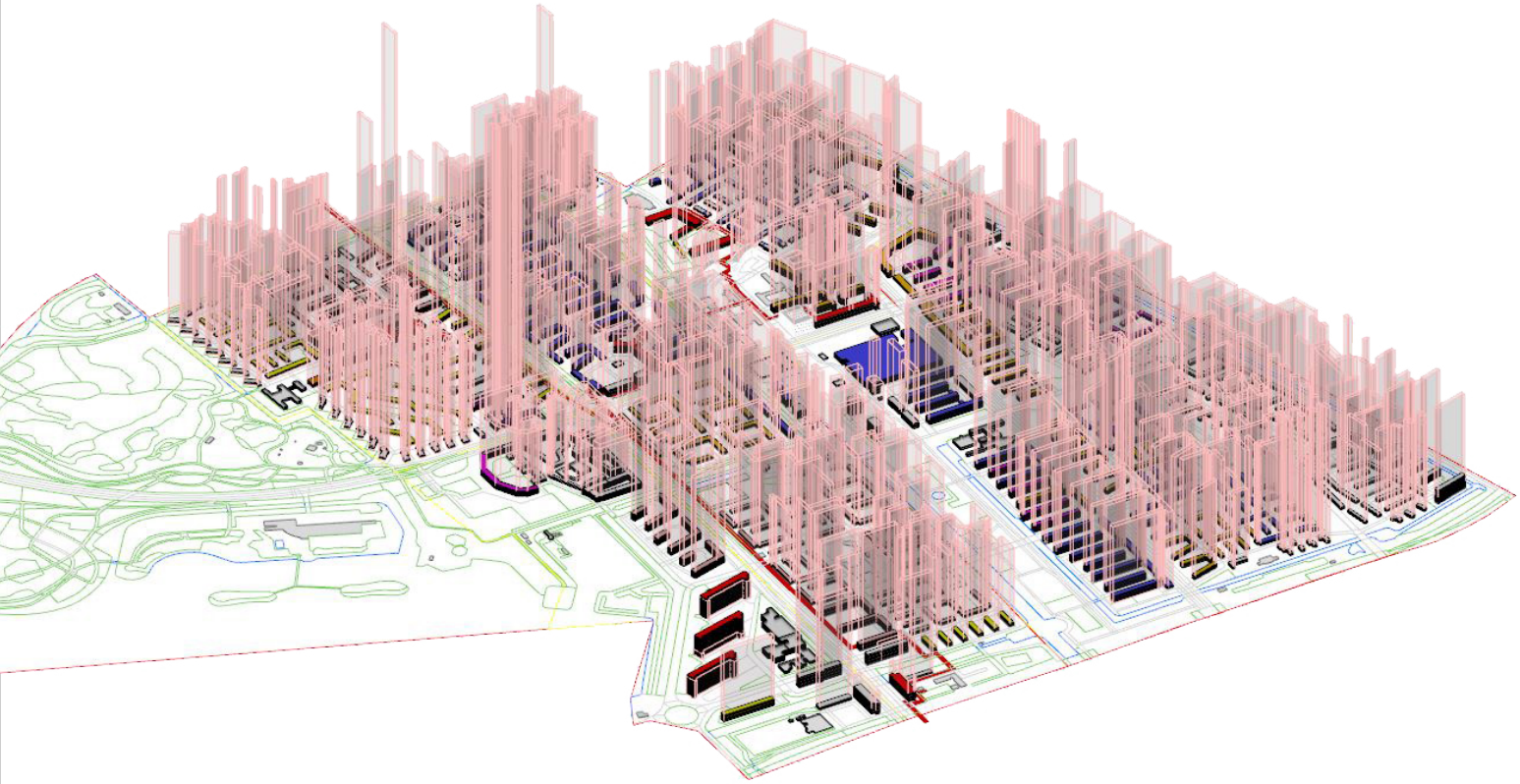

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ABBREVIATIONS

BPIE	Buildings Performance Institute Europe
EU	European Union
EPBD	Energy Performance of Buildings Directive
nZEB	Nearly Zero-Energy Building
ZEB	Zero-Energy Building
DHN	Domestic Hot Water
NOM	Nul Op de Meter (Zero On the Meter)
ATES	Aquifer Thermal Energy Storage
GSHP	Ground Source Heat Pump
COP	Coefficient Of Performance
PV	Photo Voltaic
PVT	Photo Voltaic Thermal
SC	Solar Collector
LT	Low Temperature
HT	High Temperature

SUMMARY

The starting point of this research is the urgent need for reducing the current energy consumption and CO2 emissions, that is vital to mitigate climate change and the limitation of energy sources. This target can be achieved by creating more sustainable cities, since nowadays, the built environment, of which residential buildings occupy the largest part, consumes huge amounts of energy worldwide, and have a major impact on CO2 emissions.

Based on the vision of City-Zen project of creating fully sustainable and energy (carbon) neutral smart cities, and the European commission's goal of reducing carbon emissions by 80-95% by 2050, the need for innovative solutions regarding energy efficient residential retrofitting is growing. At the same time, different and complex methods to define sustainable measures, actions and interventions are used. The current research, aims to contribute at the City-Zen project for creating a structured energy urban planning approach, by answering the following question:

Which is the methodology leading to the design of a roadmap that helps to define which energy systems and retrofit measures should be applied where and when, on residential neighbourhoods of Amsterdam Nieuw West until 2050, for achieving their energy transition and CO2 emissions reduction?

Hence, the main objective of this project is the development of a stepped methodology, to define a roadmap that leads to the goal of the energy transition and CO2 emissions reduction of residential neighbourhoods in Amsterdam Nieuw West, through the suitable combinations of energy systems and retrofit measures on the timeline until 2050.

The answer to the research question is given by developing an energy urban planning 4-step methodology, and by formulating a catalogue of energy and retrofit measures for the building, neighbourhood and district scale. The four steps are defined as the 1) mapping the present, 2) the definition of the future energy targets, 3) the development of the strategy for selecting the suitable energy systems, and eventually 4) the design of the energy transition roadmap for selected neighbourhoods inside Amsterdam Nieuw West district.

This methodology is required to be followed step by step, applying the first three steps initially on the city scale for the sake of creating a smooth transition of the steps implementation process from city scale to neighbourhood scale. These outcomes regard the definition of future energy targets scenario concentrating on heat demand, the main heat systems ratio in each district, and the classification of suitable energy systems for Amsterdam's neighbourhoods.

Furthermore, the same steps are applied on neighbourhood scale with minor changes, to get to the final step which is the roadmap design, comprised of 3 substeps. First of all, the roadmap suggests the selection of suitable energy systems for 2050 for each one of the selected neighbourhoods. The selections are based on several variables retrieved by literature review. These variables lead to solutions for smaller clusters of dwellings consisting the neighbourhoods, formulated by similar construction characteristics and ownership status. Secondly, description templates are provided, one for each energy system, listing the used energy retrofit measures in steps, and quantifying the changes in heat demand and in CO2 emissions according to each step. Finally, the collected retrofit solutions from the first two sub-steps are used in the final sub-step of defining the interventions on timeline. The changes in heat demand are visualised on 3-dimensional heat maps, showing the results of 5-year periods of retrofit actions, starting from today until reaching the final energy goal in 2050.

This thesis concludes with a structured energy urban planning methodology, that is certainly useful for Amsterdam municipality, that has an overview of the context and current energy conditions, to help give more unified solutions of energy systems and retrofit measures applications for clusters of residential building blocks. The main focus of this work, is the CO2 emissions and the heat demand reduction, not only for the selected neighbourhoods of Amsterdam Nieuw West, but also for the whole city of Amsterdam. The goals are illustrated in the running scenarios, and are set to 60% reduction for the city and 75% for Amsterdam Nieuw West district by 2050. Additionally, this approach is promising for further implementations on other cities of the world, even though the energy targets, the context and energy characteristics will probably differ, leading to the use of different energy systems. The energy transition of the selected neighbourhoods inside Amsterdam Nieuw West can be certainly achieved by following the developed roadmap. The remaining heat demands can be covered by the applied energy systems using local renewable sources. However, stakeholders play a dominant role on the decision-making and further research is required, such as interviewing the owners and asking the energy suppliers about future plans, for giving more detailed and accurate solutions.

CONTENTS

01
INTRODUCTION

1.1 BACKGROUND

1.1.1 Climate change

Climate change is a burning issue nowadays, since the consequence of the rising temperature through the last decades is becoming more and more threatening for our planet. It is a global issue that is felt also on local scales, and it is so complex that people of different dimensions, scientists and politicians, are needed for making decisions on the mitigation of climate change. The climate change results the extend of “greenhouse effect” according to most climate scientists, that constitutes the main cause of global warming, where certain gases in the atmosphere create a layer that traps heat that radiates from Earth towards space (“Global Climate Change”).

The energy services required nowadays serving the basic human needs, such as lighting, cooking, space comfort and mobility, drive to the global use of fossil fuels. Due to the burning of fossil fuels the concentration of carbon dioxide (CO2) has increased dramatically over the last century. Historically, it is proven that CO2 concentration has increased by more than a third since the beginning of the Industrial Revolution. CO2 is the main substance of the atmosphere “forcing” the climate change (Pachauri et al., 2014).

Additionally, the building sector plays an important role in CO2 emissions since buildings account for 40 % of total energy consumption in the Union, where residential buildings occupy the biggest part. As the building sector expands, the need for the energy use expands too. Consequently, important energy measures for the reduction of energy consumption, and for the production of energy through renewable sources need to be applied on existing and new buildings, in order to reinforce the Union’s independency on energy produced by fossil fuels. In this way, the resulted CO2 emissions will also be reduced (DIRECTIVE, 2010/31/EU).

1.1.2 EU2020 to EU2050 goals

The European Union has developed a strategy that has to be followed by all its members for reaching the goals set for keeping the global temperature increase below 2°C, with CO2 emissions and energy demands reduction from 2020 to 2050. One of the first countries that have already adopted and started implementing this strategy is the Netherlands. The aim for the EU Member States is to reduce emissions by at least 20% below 1990 levels by 2020, and by 80-95% by 2050. According to the low-carbon economy roadmap of the European Commission, the low-carbon transition is feasible and affordable by setting milestones to achieve 40% emissions cuts by 2030 and 60% by 2040, and with the contribution of all sectors (“2050 Low-Carbon Economy - Climate Action - European Commission”).

Regarding the building sector, a percentage of 90% emissions reduction is possible for dwellings and office buildings, and the reduced energy bills are expected to recover the investments through time. The ways for the energy transition of the building sector are through the passive housing technology of new buildings, the refurbishment of existing buildings (insulation of buildings and more efficient comfort installations), and the substitution fossil fuels by local renewables for satisfying the needs for heating, cooling, cooking and other energy depended human activities. The electricity is going to come from renewable sources, such as wind, sun, water and biomass (Rohde et al., 2012).

1.1.3 Amsterdam’s need for energy retrofit measures

Amsterdam is one of the cities that intend to become climate friendly and energy efficient until 2050 and totally independent of fossil fuels in later plans. Amsterdam have already started following the practical climate ambitions recommended by the Intergovernmental Panel on Climate Change (IPCC) for developed countries, and is going to strive to achieve a 75% emissions reduction in CO2 by 2040 and 100% by 2050.

For the energy transition of the city the ways already mentioned are followed, regarding the new buildings energy efficiency, the old buildings refurbishment and the use of renewable energy technologies. As the existing residential buildings cover the most of the Amsterdam’s built area, there is an urgent need to bring retrofit and energy measures into action. Some of these measures are already used, others are under development, and there is a lot of research already conducted for residential retrofit of the typologies in the Netherlands, and thus in the city of Amsterdam (Municipality of Amsterdam, 2015).

1.1.4 Energy urban planning and REAP approach

Under the energy goals for the mitigation of climate change, energy efficiency and CO2 emissions reduction can be achieved more sufficiently when the interventions are made on bigger scales, with a variety of renewable sources being connected with the energy infrastructures of the cities. Also, by using the energy district networks, and the waste heat or free cooling from the low-exergy energy sources, the energy consumption in new and existing buildings can be considerably reduced. By using energy saving measures on individual buildings and connecting them to the district heat network can be more cost effective than a full retrofit, not in all cases though. (Energy, R., 2013). Thus, actions for optimising the building elements of single building blocks, neighbourhoods and districts are required for a holistic energy upgrade approach of urban areas (Strasser & Helmut, 2015).

Through the Rotterdam Energy Approach and Planning (REAP), in order to transform the city of Rotterdam to CO2 neutral until 2025, a methodology serving the energy urban planning was developed based on the New Stepped Strategy. This strategy suggests firstly the reduction of the energy demand through smart and bioclimatic design, by considering the built area as a part of the context, secondly the reuse of waste streams, and finally the use of renewable sources and the reuse of waste as food to complete the remaining energy needs. Also, it can be applied in all scales, from the building, to the neighbourhood, to the district and to the city respectively (Tillie et al., 2009).

1.1.5 City-Zen approach and vision for Amsterdam Nieuw West

The general vision of the European City-Zen project aims at creating clean, smart and cooperative cities with a high level of liveability and prosperity, where decision makers and citizens work together. Data exchange between infrastructures is very important for effective investments and the achievement of Zero (carbon) energy cities. The objective of this project is to provide cities and citizens with methodologies to help them achieve the EU energy goals of 2020 and beyond. A catalogue of different sustainable measures is under development to give solutions on technical and non-technical level to integrate strategies where suitable interventions are determined on a timeline (Broersma & Fremouw, 2015).

The Amsterdam Nieuw West district is one of the demonstration projects of urban energy master planning with short term and long term sustainable interventions of the City-Zen approach. Under the scope of transforming the area in an energy/ carbon neutral district and improve the inhabitants' quality of life, different strategies are defined, such as smartifying the e-grid, the retrofit of existing residential building and the improvement and expansion of the district heat grid ("City-Zen"). As the efficiency requirements of the new buildings are expected to have a limited impact in energy consumption reduction, since the average build rate is assumed as 1% per year, the attention is directed on existing buildings (Broersma & Fremouw, 2015).

1.1.6 Problem formulation

Based on the vision of City-Zen project of creating fully sustainable and energy (carbon) neutral smart cities, and the goal of EU for carbon emissions reduction 80-95% by 2050, the need for innovative solutions for district heating expansion, smartifying the e-grid and for energy efficient retrofitting is created. In this project, the retrofit of residential buildings is emphasised since the majority of the 2050 buildings already exists.

The cities' built environment not only consume a major part of energy production worldwide, but also, have a major impact on CO2 emissions, while the residential buildings constitute the biggest part of the building stock. A drastic reduction of energy and CO2 emissions is crucial for the mitigation of climate change and energy sources shortages. Under the aim of creating more sustainable cities, different and complex methods to define sustainable measures, actions and interventions are usually used.

1.2 PROBLEM STATEMENT

There are several existing strategies to deal with the retrofit of different residential typologies. Moreover, for Amsterdam Nieuw West there is not a clear structured approach for residential retrofit interventions referring to different scales.

Hypothesis

Until today, most of the retrofit projects resulted individual building retrofit attempts. However, the optimal energy performance results can be achieved with their connection to the city's improved energy networks. Based on this hypothesis, the solutions for optimizing the retrofit of residential buildings affect and have to be made on different scales in Amsterdam Nieuw West. However, in this project, the interventions will be optimized on neighbourhood scale, while taking into consideration also the district and building scale.

Final product

A stepped methodology that guides to the creation of an energy transition roadmap with residential retrofit interventions on a timeline, for the neighbourhoods with different site energy conditions, referring to neighbourhood combinations inside Amsterdam Nieuw West district. The roadmap includes a decision-making flowchart for selecting energy systems, one filled out template for each energy system describing the on-site applications of suitable combination of energy saving measures and renewable energy technologies, and the after-retrofit energy need for heating, for electricity regarding the heat pumps and the decrease in CO2 emissions. The retrofit steps on timeline and the changes in heat demand will be visualised through 3-dimensional visualizations.

1.3 OBJECTIVES

The main objective is the development of a stepped methodology, to define a roadmap that leads to the goal of the energy transition and CO2 emissions reduction of residential neighbourhoods in Amsterdam Nieuw West, through the suitable combinations of energy systems and retrofit measures on the timeline until 2050.

Sub-objectives

- Collect data concerning the current energy demands and potentials of Amsterdam city.

- Determine specific energy goals for Amsterdam city and Amsterdam Nieuw West district.

- Organise the energy and retrofit measures in a catalogue concerning different scales.

- Organise the residential building blocks with the similar construction and ownership characteristics in clusters.

- Define the suitable energy systems for the residential clusters inside each neighbourhood

- Determine optimized combinations of energy and retrofit measures for each case and calculate the energy performance after retrofit

- Determine the appropriate time for retrofit interventions

1.4 RESEARCH QUESTIONS

Which is the methodology leading to the design of a roadmap that helps to define which energy systems and retrofit measures should be applied where and when, on residential neighbourhoods of Amsterdam Nieuw West until 2050, for achieving their energy transition and CO2 emissions reduction?

Sub-questions

- Which are the current energy demands and potentials of Amstedam city?

- Which are the future energy goals until 2050?

- Which are the suitable energy systems and the retrofit measures that can be applied on building, neighbourhood and district scale?

- Which residential typologies exist in Amsterdam Nieuw West neighbourhoods and which are their ownership and energy characteristics?

- Which neighbourhood should get which combination of energy systems and retrofit measures and when?

- Which are the decision points of the roadmap for the different neighbourhoods in Amsterdam Nieuw West with retrofit interventions on timeline?

1.5 APPROACH AND METHODOLOGY

For the development of the present graduation project, a literature review was preceded for the formation of a valid basis. The main objective is the development of an energy urban planning methodology, leading to the roadmap design for achieving the goal of the energy transition and CO2 emissions reduction of residential neighbourhoods in Amsterdam Nieuw West, through the suitable combinations of energy systems and retrofit measures on timeline until 2050. The general research framework used, follows a combination of the approaches of design by research and research by design.

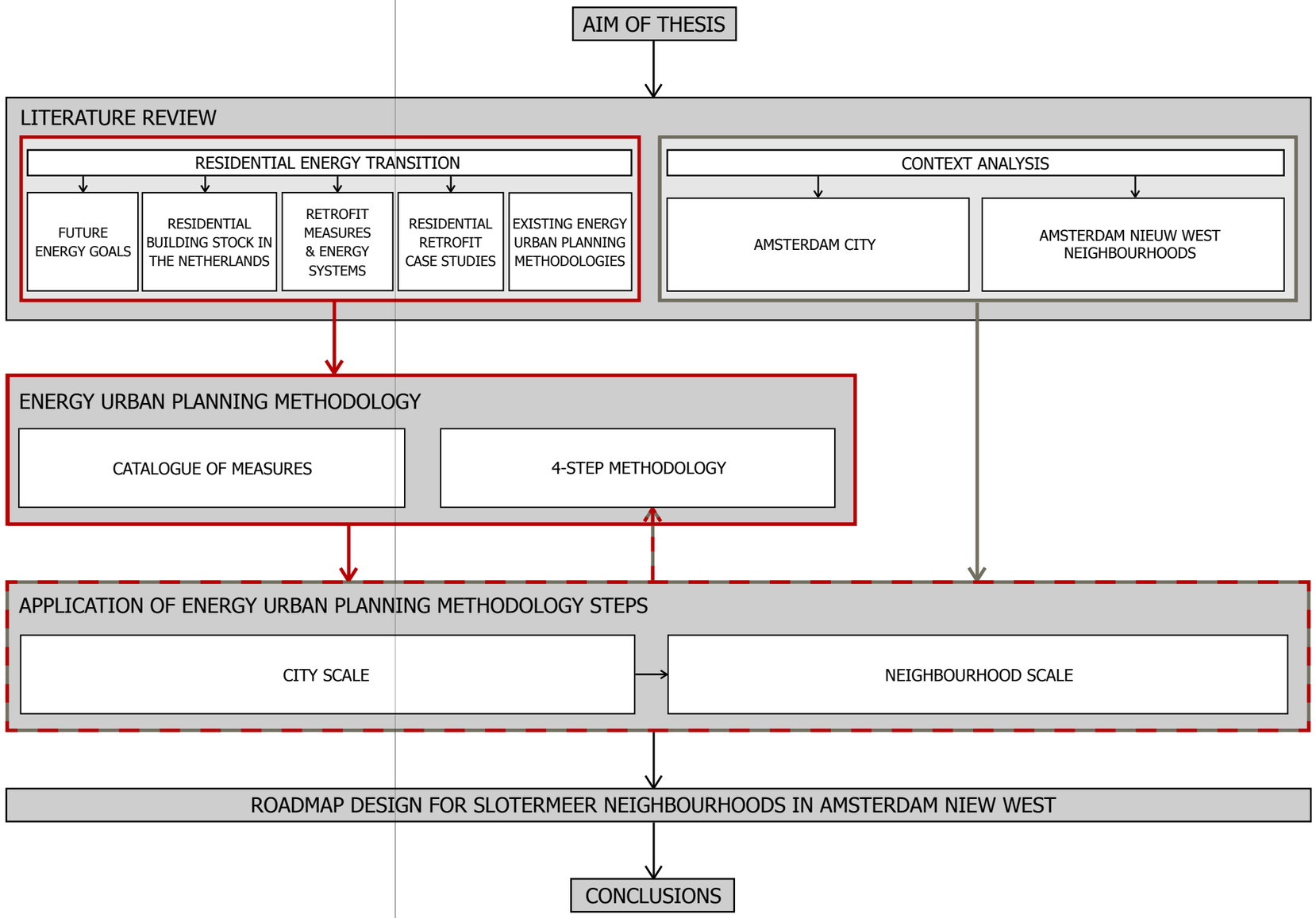
In order to accomplish the aim of the project, the basic steps followed are:

1. The literature review regarding the energy retrofit of residential buildings, and the context analysis of Amsterdam city and of neighbourhoods in Amsterdam Nieuw West district.

2. The development of an energy urban planning methodology, where the energy and retrofit measures are organised in a catalogue and a 4-step methodology is developed.

3. The application of all collected information according to the 4-step methodology on city and neighbourhood scale respectively.

4. The final roadmap design for the energy transition of the neighbourhoods in Amsterdam Nieuw West.



1. Literature review

For the first part of the literature study, different aspects of residential energy transition are analysed. The first aspect concerns the European commission's and Amsterdam Municipality's future energy goals until 2050, to help define the energy goals for this project. The second aspect refers to the existing residential building typologies in the Netherlands, to get an image and identify them accurately during the context analysis. The typologies are retrieved by the European project Tabula ("TABULA Webtool"), where the requirements for the energy need for heating per typology are also gathered.

Furthermore, extended research on retrofit measures and energy systems is conducted, in order to understand which measures reduce, reuse or produce energy, and how the energy systems work. Additionally, case studies of residential retrofit contribute in identifying the scale applicability of the different measures. The information on measures of all kinds of scales is useful to recognize the optimal solutions for neighbourhoods, as the aim of the project indicates. The last aspect investigated under the topic of residential energy transition, regards the existing energy urban planning methodologies. The knowledge earned from this aspect is essential for the formulation of a stepped methodology in later stage, to lead to the creation of the energy transition roadmap of residential neighbourhoods.

The next step is the context analysis referring to Amsterdam city and to Amsterdam Nieuw West neighbourhoods, to use the relative data for applying the steps leading to the final roadmap design. Starting from the context analysis of Amsterdam city, proposals for specific alternative energy systems, that can replace in the future the use of natural gas are studied. The current energy demands of natural gas and electricity, as well as the energy potentials offered from renewable sources, are found in the Energy Atlas of Amsterdam Southeast (Geert den Boogert et al., 2014). By knowing the energy potentials from each source, the most suitable systems can be classified. A list of requirements for applying each system is crucial to help define the variables that determine for which neighbourhood each system is most suitable. The mentioned energy potentials refer to the renewable sources of sun, wind, water, geo, domestic waste, biomass and waste heat from buildings and industries.

Regarding the context analysis of neighbourhoods in Amsterdam Nieuw West district, the first step was to determine a smaller number of neighbourhoods for retrofit interventions, due to the limited time for this project, leading to the selection of the Slotermeer-Zuidwest and Slotermeer-Noordoost neighbourhood combinations. An extraction of data concerning the description of each dwelling (e.g. the housing typologies, the ownership, the construction year) and the energy consumption (e.g. gas, electricity and the resulting CO2 emissions) was conducted. The local energy potentials are identified as well (Haan).

2. Energy urban planning methodology development

In this chapter, the research on the energy systems and retrofit measures, and case studies regarding their on-site applications, contributes in the definition of a catalogue of measures, according to their energy characteristics (reduce, reuse or produce), and their application scale (building, neighbourhood, district). This catalogue includes the solutions that are used at the stage of the roadmap design, to define on-site energy retrofit applications inside each neighbourhood. Moreover, after an overview of existing energy urban planning methodologies, a 4-step methodology is developed in order to get to the final result of the roadmap for the selected residential neighbourhoods of Amsterdam Nieuw West, starting the process of energy transition from the city scale, to get step by step to the neighbourhood scale.

3. Application of energy urban planning methodology steps

At this point, all data from the preceded literature review and context analysis is used to implement the stepped approach shown in the following figure, of 1) mapping the present, 2) defining the future energy targets, 3) developing strategy for selecting suitable energy systems, and finally 4) get to the desired roadmap design aiming the energy transition of residential neighbourhoods. The first 3 steps, are initially applied on the city scale to get to the outcomes of the main (high and low temperature) heat systems ratio in each district, and of classifying the suitable systems for Amsterdam's neighbourhoods.

Afterwards, the stepped methodology indicates to go back to step 1 and apply the steps for the selected neighbourhoods in Amsterdam Nieuw West. In order to get to step 4, the roadmap design, a decision-making diagram is developed, that helps to select the suitable energy systems for applications on the appropriate time for each neighbourhood. This decision-making tool contributes in categorizing the dwellings in clusters consisting the neighbourhoods, based on defined variables regarding their construction and ownership characteristics, guiding to the suitable energy system for each case.

4. Roadmap design

For accomplishing the design phase of the roadmap 3 sub-steps are required, 1) the selection of suitable energy systems for 2050 for each one of the selected neighbourhoods, 2) the description of the energy system and retrofit measures, and the corresponding changes in heat demand and CO2 emissions that are listed in templates, and 3) the definition of the interventions determined by the 2 previous sub-steps on timeline, starting from today and ending in 2050. The first stage is to apply the decision-making diagram to define the suitable energy systems for the clusters inside each neighbourhood. The already collected data through literature review gives answers to the variables guiding the selection of systems, thus forming the 2050 vision for Slotermeer neighbourhoods. In the next stage, description templates are filled out, one for each basic energy system, listing the energy saving measures and renewable energy technologies applied on different clusters, through the steps of reduce, reuse and produce heat, to fulfill the remaining heat demand after reduction, including also the produced electricity to satisfy the need for heat pumps' operation, when low temperature heat systems are applied. For the completion of the roadmap, all variables for choosing systems

and for prioritising dwellings for interventions, are used to determine the retrofit steps on a timeline to the energy transition of the area, illustrating on three-dimensional heat maps the changes in heat demand at 5-year intervals.

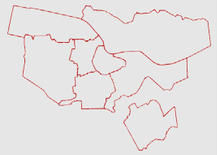
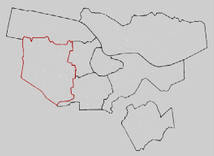
Boundary conditions

- The intervention site is restricted in fewer neighbourhoods inside Amsterdam Nieuw West than intended at the beginning of the research, due to the time limit for the project conduction

- Several scenarios were developed allowing to follow the process step by step, like the average efficiency of the currently used boilers, the gas and electricity amounts in 2050, the high temperature and low temperature availability in 2050, and the heat demand reduction for the whole city and separately for the selected neighbourhoods inside Amsterdam Nieuw West.

ENERGY URBAN PLANNING METHODOLOGY STEPS

Leading to the roadmap final design

	Step 1 Map the present	Step 2 Define future energy targets	Step 3 Strategy for selecting energy systems	Step 4 Roadmap design
 Amsterdam city	Step 1a Energy demands Step 1b Energy potentials	Step 2a Future scenario for natural gas and electricity use Step 2b Desired future heat demand	Step 3a Develop scenario for dividing the main heat systems through the districts of Amsteram Step 3b Main heat systems ratio in each district Step 3b Classify energy systems	
 Amsterdam Nieuw West neighboorhoods	Step 1a Site determination inside Amsterdam Nieuw West Step 1b Buildings description & Energy demands Step 1c Energy potentials	Step 2a Desired future heat demand Step 2b Low and high temperature heat potentials & technologies for each system	Step 3a Set variables for selecting the suitable energy system Step 3b Set priority criteria for on-site interventions Step 3c Develop decision-making diagram for on-site interventions on appropriate time	FINAL DESIGN Step 4a Define suitable energy systems in 2050 for each neighbourhood Step 4b Describe energy systems and retrofit measures leading to 2050 vision Step 4c Define the interventions on timeline

1.6 PLANNING AND ORGANISATION

Graduation Project

	Start Week	Nov 7, 2016

	Starting	Nov 7	Nov 14	Nov 21	Nov 28	Dec 5	Dec 12	Dec 19	Dec 26	Jan 2	Jan 9	Jan 16	Jan 23	Jan 30	Feb 6	Feb 13	Feb 20	Feb 27	Mar 6	Mar 13	Mar 20	Mar 27	Apr 3	Apr 10	Apr 17	Apr 24	May 1	May 8	May 15	May 22	May 29	Jun 5	Jun 12	Jun 19	Jun 26
	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Literature review for Residential energy retrofit	**P1**																																	
	Residential building stock in the Netherlands																																	
	Buildings energy performance definitions																																	
	Energy retrofit measures																																	
	Case studies																																	
Context analysis of Slotermeer-Zuidwest area in Amsterdam Nieuw West district	Residential typologies																																	
	Energy demands of existing residential buildings																																	
	P2 report and presentation																																	
	P2																																	
	Evaluation of P2 report and presentation																																	
	Energy potentials of the area																																	
	Categorization of neighbourhoods																																	
Toolbox of energy retrofit measures for "Dutch cities"	Organisation of energy retrofit measures																																	
	Quantification of measures																																	
	P3 report and presentation																																	
	P3																																	
Roadmap for site specific residential energy retrofit	Evaluation of P3 report and presentation																																	
	Application of energy retrofit measures on each neighbourhood																																	
	Design representation of measures																																	
	Calculation of electricity, heat demands & CO2 avoidance																																	
	Define interventions on a timeline																																	
	P4 report and presentation																																	
	P4																																	
Final Result	Evaluation of P4 report and presentation																																	
	Evaluation of measures combinations and energy results																																	
	Conclusions																																	
	Format of P5																																	
	P5 report and presentation																																	
	P5																																	

1.7 RELEVANCE

Societal relevance

Socially related, people who are involved in the residential retrofit of areas are benefited from this project. Not only the consultant engineers and the architects are included, but also the residents of the buildings. The energy retrofit results in preservation of existing dwellings which is a sensitive topic for the residents, and in a better quality of living. Additionally, the energy savings and the avoidance of using fossil fuels, contribute in the reduction of energy bills and generally in the mitigation of climate change that affects everyone without exception.

Scientific relevance

In the scientific aspect, first of all, the project is directly related to the City-Zen project that aims at a roadmap development for the energy transition of urban areas, and the creation of clean, smart and cooperative cities with a high level of liveability and prosperity. Also, the energy transition of Amsterdam Nieuw West is one of the current projects of City-Zen. This project, intends to contribute in City-Zen project by giving possible retrofit solutions for a part of Amsterdam Nieuw West, as well as, by creating a roadmap that can be used further the energy optimization of other residential districts.

02

RESIDENTIAL ENERGY RETROFIT

2.1 ENERGY GOALS

In this sub-section, the future energy goals set by the European commission and Amsterdam municipality are presented and summarized, contributing in defining the 2050 goal for this project at a later stage, regarding Amsterdam city and Amsterdam Nieuw West district.

2.1.1 European commission's energy goals

Current environmental events like the increase of average global temperature on Earth due to the greenhouse effect have driven European Union to define more strict energy priorities for the next coming years. Hence, EU has announced the 2020 Energy Strategy that aims, from the timespan between 2010 and 2020, 1) to achieve at least 20% reduction in greenhouse gases emissions, 2) to expand the current share of renewable energy within EU to at least 20% of consumption and 3) to overall ameliorate the energy efficiency by at least 20%.

Moreover, EU countries reach a consensus about the objectives that should be achieved by 2030 regarding their energy strategy. This set of objectives includes a significant reduction of at least 40% in greenhouse gas emissions as well as an increase of the amount of renewable energy with no less than 27%. In addition, EU countries also agreed to an energy efficiency increase at least 27%, which will be assessed by EU with the potential of raising the goal to 30% by 2030. Finally, EU countries agreed on the completion of the internal energy market by achieving 15% electricity interconnection among them as well as the encouragement of developing important infrastructure projects. By complying with the aforementioned goals, Europe should be able to achieve a rather notable reduction of 60% regarding greenhouse gas emissions by 2040 with even greater reduction between 80% and 95% compared to 1990 levels by 2050

2.2.1 Amsterdam municipality's energy goals

Following EU's vision, that aims in a substantial reduction of greenhouse gas emissions, Amsterdam aims to be fossil fuel-free by defining several strict goals. The municipality of Amsterdam aim for a 20% increase in renewable energy production by promoting wind and solar energy as well as by making more use of renewable heating. Another goal is to shrink the energy usage by 20% compared to 2013, by providing sustainable solutions to existing housing stocks as well as by promoting energy-neutral construction. Another measure is the reduction of energy consumption by corporate real estate and social real estate. Consequently, these measures will lead to a reduction in usage of fossil-based energy and simultaniouslty to a substantial increase of renewable energy production. This outcome will result in lowering Amsterdam's greenhouse gas emissions by 40% and 75% by 2025 and 240 respectivley compared to 1990 (source: Structuurvisie Amsterdam 2040). Current CO2 emissions are at 4,437 kilotons a year.

Nevertheless, achieving the goals, that were mentioned previously, implies that current measures which aim for energy generation and energy saving should be accelerated. Municipality of Amsterdam aims for a further expansion of the district heating grid as well as to make more use of wind and solar sources. Hence, the new goals, regarding renewable sources like wind and solar, are set for 18 megawatt (MW) of extra wind energy, 150 MW of extra solar energy (around 950,000 square metres of solar panels). In addition, they aim for a substantial expansion of the district heat grid with approximately 102,000 connections. Furthermore, new potential measures regarding biomass such as heat generated by waste energy plant should be exploited too.

The following table shows an overview of the future energy milestones, defined by the European commission and the municipality of Amsterdam, in percentages concerning the energy reduction, the share of renewables, and the CO2 emissions reduction.

EU2020 to 2050

Comparing to 1990	2020	2030	2040	2050
Energy reduction	20%	27%	-	-
Share of renwables	20%	27%	- 50%	-
CO2 reduction	20%	40%	60% 75%	80-95% 100%

Table 1: Future energy targets overview

Amsterdam municipality's goals

2.2 RESIDENTIAL BUILDING STOCK IN THE NETHERLANDS

Residential and non-residential buildings result the two main categories that the building stock can be divided into. There are different types like offices, commercial buildings, schools, hospitals, apartment buildings, terraced or detached houses etc. This project focuses on the retrofit of residential buildings, and knowledge about the age of the building, the typology, the size, the constructional features and the ownership is necessary for the identification of possible retrofit options. Also, not only the energy demands of the building blocks are needed, but also, the energy potentials offered by the excess energy of surrounding buildings with different functions and from renewable sources.

Understanding the typology and age of the housing stock in the intervention area will help to identify what types of measures will be most effective and which should be promoted on the buildings in the area. The age of the building is useful as it indicates information about their construction type. This is a fact that applies not only in the Netherlands, but also, in the whole Europe. In the Netherlands, like in other European Countries, it is considerable that many residential buildings were built massively after World War II (figure 1), and it is also important that building regulations that mandate thermal insulation of building envelopes were introduced after the 1970s resulting in the poorly insulated majority of houses. Common construction and energy characteristics recognized among different housing blocks, contribute to determine retrofit strategies that can be applied more effectively on bigger scales, and in optimized solutions for different neighbourhoods (Konstantinou, 2014).

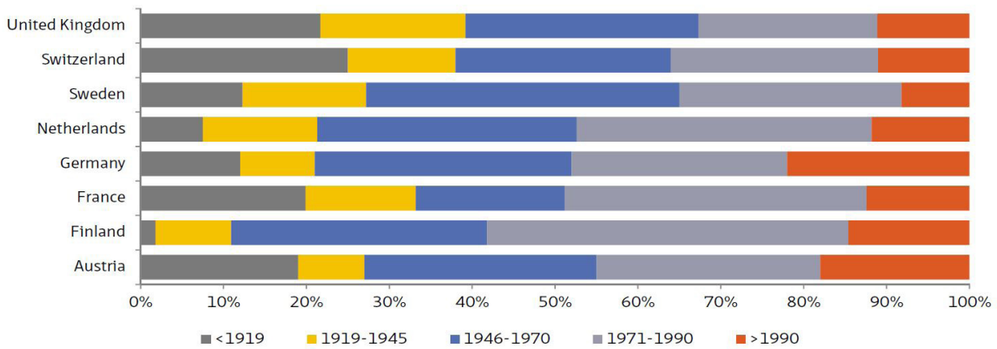


Fig. 1: Age distribution of the residential building stock (source: Itard and Meijer,2009, p. 35)

2.2.1 Existing residential typologies

Regarding the different existing residential typologies in the Netherlands, they are distinguished from their position in relation to other dwellings in the neighbourhood and from the number of housing units in one building block (Konstantinou, 2014). Based on the main results of the episcope project, which is involved with the Monitor Progress Towards Climate Targets in European Housing Stocks, the basic typologies in the Netherlands are the single-family houses, the terraced houses, the multi-family houses and the apartment blocks (figure 2). In the following figure, the typologies are also categorized based on their region, their construction year class and their additional classification. In further study, the additional classification for the single-family houses is detached or semi-detached house, for the terraced is middlerow or endhouse, for the apartment blocks it is gallerijflat or portiekflat, and the multifamily-house are also named as maisonettes (“NL The Netherlands”). The housing typology is important for the identification of information concerning the energy performance and specific construction characteristics that is crucial for the decision of which retrofit measures should be combined (Konstantinou, 2014).

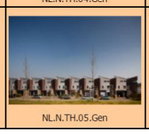
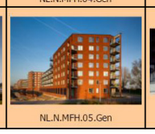
	Region	Construction Year Class	Additional Classification	SFH Single-Family House	TH Terraced House	MFH Multi-Family House	AB Apartment Block
1	national	... 1964	generic	 NL.N.SFH.01.Gen	 NL.N.TH.01.Gen	 NL.N.MFH.01.Gen	 NL.N.AB.01.Gen
2	national	1965...1974	generic	 NL.N.SFH.02.Gen	 NL.N.TH.02.Gen	 NL.N.MFH.02.Gen	 NL.N.AB.02.Gen
3	national	1975...1991	generic	 NL.N.SFH.03.Gen	 NL.N.TH.03.Gen	 NL.N.MFH.03.Gen	 NL.N.AB.03.Gen
4	national	1992...2005	generic	 NL.N.SFH.04.Gen	 NL.N.TH.04.Gen	 NL.N.MFH.04.Gen	 NL.N.AB.04.Gen
5	national	2006...2014	generic	 NL.N.SFH.05.Gen	 NL.N.TH.05.Gen	 NL.N.MFH.05.Gen	 NL.N.AB.05.Gen

Fig. 2: Age distribution of the residential building stock (source: http://webtool.building-typology.eu/#bm)

2.2.2 After retrofit heat demand per typology

In the current sub-section, a research is conducted that concerns the heat demands that can be reached after applying deep retrofit measures on the existing typologies in the Netherlands. This research is required for the indication of the expected values, that not only depend on the residential typology, but also, on the construction year class (table 2).

There is a variety of possible energy retrofit measures that can be combined in several ways. For instance, energy savings can be achieved by improving the performance of the building envelope and recovering heat from the ventilation losses, and energy production by significant use of solar panels or renewable - based district heating. These examples of measures are limited comparing to the existing and under development range, and it is certain that each combination is a direct result coming from the available local solutions and sources. The buildings require different combinations of measures based on their location, form, orientation, climate severity, period and quality of construction, and other possible factors (Mørck et al., 2014).

Construction year class	Single-Family House	Terraced House	Multi-Family House	Apartment Block
... 1964	48.0	43.8	40.7	41.7
1965...1974	46.2	41.2	36.7	37.0
1975...1991	43.8	39.3	38.2	39.3
1992...2005	43.9	37.5	36.5	35.7
2006...2014	40.9	35.5	33.7	34.8

Table 2: Total primary energy demand for Heating and DHW (kWh/m²) per typology (source: http://webtool.building-typology.eu/#bm)

2.3 RETROFIT MEASURES

The energy retrofit measures aim at reducing the energy consumption for existing buildings. For achieving the optimal energy performance results of a building, there should be a balance between the rational use of energy and the production of energy in order to complement the remaining energy needs. Based on this fact, in this project, the energy measures are separated in the three main categories of energy saving measures (reducing the energy use in existing dwellings), energy exchange (between buildings and building zones), and renewable energy technologies (producing energy in building and district scale).

Different measures used for retrofitting houses for the reduction, reuse and production of energy are illustrated on the following table:

Exterior walls insulation	Waste heat recovery for district heat network	Photovoltaic's (PVs)
Roof insulation	Waste heat recovery for building heating	Solar Collectors (SC)
Ground floor/basement ceiling/basement wall insulation	Energy exchange between building zones	Photo Voltaic Thermal systems (PVT's)
High-performance windows	Energy exchange between buildings	Heat pumps (ground source, air, water or waste heat)
Energy efficient lighting	Energy cascade	Deep Geothermal systems
Shading systems - Solar protection	Smart appliances (dishwasher, clothes washer & dryer, Refrigerator, water heater)	Aquifer Thermal Energy Storage (ATES)
Efficient mechanical ventilation system (with heat recovery)		Road collectors with ATES
Shower heat exchangers		Waste-to-energy district heating plant
Smart meter		District heating boiler fuelled by electricity, biogas, wood pellets, wood chips (usually as backup heating systems)
		Combined Heat and Power (CHP) system fuelled by biogas or biomass
		Wind turbines

Table 3: Retrofit measures per energy property (sources:http://www.ashraeasa.org/pdf/TVVL-study--Roadmap-to-nZEB--2014.pdf, Konstantinou, 2014)

2.4 RENEWABLE ENERGY SYSTEMS

"District energy is being developed in the 45 champion cities because of its ability to dramatically reduce the carbon intensity of heating and cooling, lower energy costs, improve air quality, increase the share of renewables in the energy mix, reduce reliance on fossil fuels and energy imports, and increase the resilience of cities" (Energy, R., 2013). In this process, synergies between the supply and production of heat, cooling, electricity and DHW are developed through a variety of technologies. In figure 3, the historical development of district energy networks and the associated energy producers and receivers, for four generations starting from the 1880s and end up to 2020-2050 that expresses the fourth one. For dutch housing, heating space and DHW is the main concern, that can be achieved by several renewable energy systems, some in combination with DHN and some not, described in the following paragraphs.

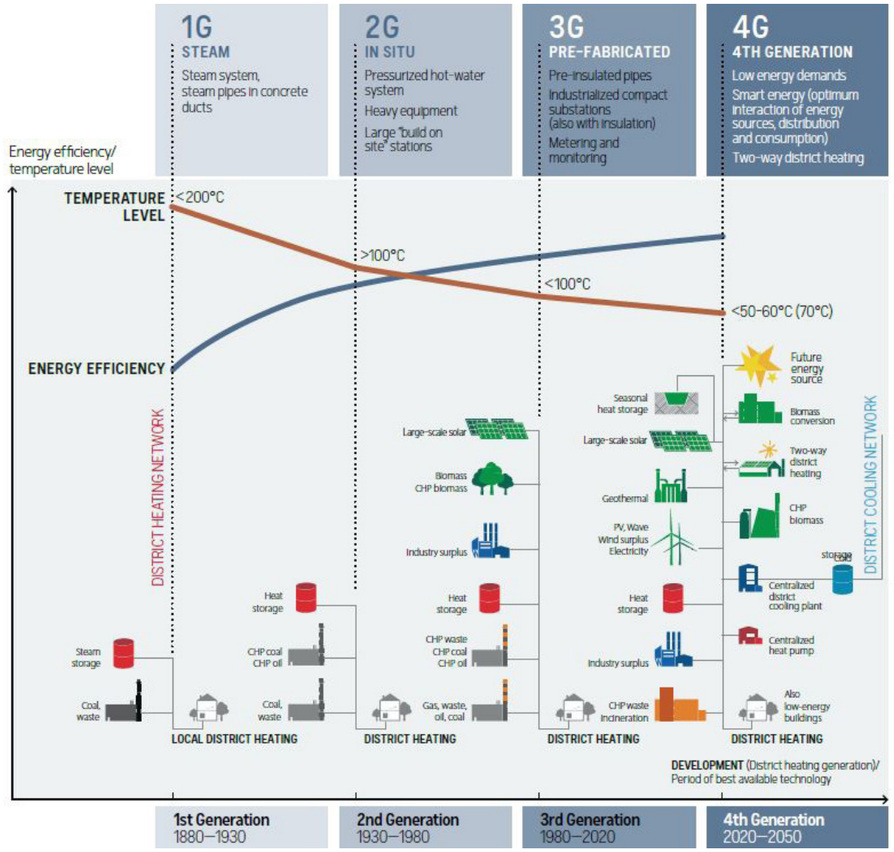


Fig. 3: Historical development of district energy networks (source: http://wedocs.unep.org)

District heating network (DHN)

District heating makes efficient use of the waste heat of energy and waste plants. However, the urban heat network can also make use of biomass, heat pumps, heat storage, solar boilers and other various technologies (see figure 5). The system works as follows: water at high temperature (approximately 100 ° C) is conveyed to the city through a primary conduit. In secondary networks, the heat will be further transported for building heating, floor heating and hot water. The temperature in the secondary networks is lower (around 70 ° C), 40 ° C) return). In Amsterdam, each year 5000 households connect to district heating networks ("Stichting Warmtenetwerk").

Fig. 4: District heating pipe in Tübingen, Germany (source: https://en.wikipedia.org/wiki/District_heating)

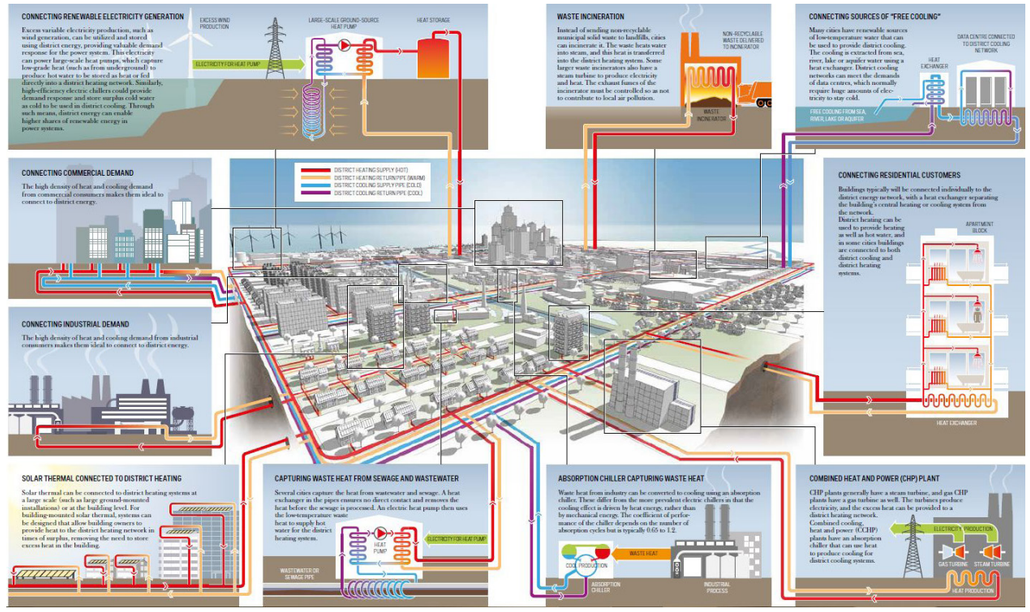


Fig. 5: District heating network energy sources and end-users (source: http://wedocs.unep.org)

Small-scale heat network connected to ATES

Excess heat or cold from local businesses and processes can be stored in ATES and be provided in a Low Temperature heat network in order to heat a residential neighbourhood and cool buildings with cooling demands. This system is especially suitable for large residential buildings, hospitals, offices or shopping centers, greenhouses and industrial sites. ATES system operates in a seasonal mode where the cooled water used in Summer reaches ± 7 °C and the heated water can reach a maximum of 15-20 °C ("Technieken: Ondiepe Bodemenergie - Opensystemen | RVO.NI").

"In an open-loop TES system the surface water is in contact with the water from a depth of 50 to 150 metres below the surface via a limited number of pipes. The groundwater is pumped to the surface and via a heat exchanger, then returned via an injection well. Variants of open-loop TES include doublet, mono-source and flow-through systems." (Geert den Boogert, L. H. (2014). Energy Atlas Amsterdam Southeast)

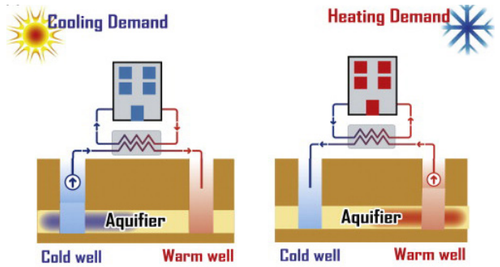


Fig. 6: ATES system in Summer (left) - in Winter (right) (source: (Bloemendal, Olsthoorn and Boons 104-114)

Fig. 7: ATES summer operation for cooling (left) - ATES winter operation for cooling (cooling) (source: http://www.underground-energy.com/ATES.html)

ZERO-ON-THE-METER (NOM)

With a NOM house, all incoming and outgoing energy flows annually into balance. The NOM is a concept to make the transformation of existing buildings into zero energy buildings, simpler, cheaper and faster. The concept of NOM provides a local structure, professional advice and cheap financing in the form of a foundation at district or village level. It allows homeowners are able to realize energy savings and sustainability without investing own money.

Every building needs a specific approach to make the house zero energy with the lowest budget. But the first step is always lowering the energy demand and avoiding heat losses as much as possible. Principles like energy efficient lighting, demand-response appliances, home energy manager, grey water recovery, wall and roof insulation, high performance thermal windows/doors, geothermal heating and cooling system and high efficiency heat pump could be used. The next step is adding principles that produce energy like wind power systems, solar thermal heating systems and solar panels ("Nul Op De Meter").

All-electric

In all-electric buildings, gas is no longer used, and only electrical systems are used for space heating and for DHW. Just like NOM system, first lowering the energy demand is needed, and high efficiency appliances can be used as well as energy production techniques. However, it does not mean that the building will reach the balance of energy consumption and production through the year. Especially in the case of high rise dwellings that the roof area offered for PVs and SCs cannot cover the total demand for electricity, heating and hot water (Gemeente Amsterdam, 2016).

Fig. 8: NOM 'ZURINGHOF' (source: https://materia.nl/article/zuringhof-smart-facade-isolation/zuringhof-zero-on-the-meter-partly-because-smart-facade-isolation-7/)

Green gas

Green gas is a general name for all gases that replace natural gas and it is produced from biomass. Green gas mainly consists of methane (CH4) and can be also called as SNG. SNG stands for Substitute Natural Gas and is fully exchangeable with fossil natural gas. Green gas has the same characteristics and specifications as fossil natural gas and makes use of the existing infrastructure. Biomass can be converted to green gas by the gasification process with efficiency of approximately 70%. Gasification is an innovative process that decreases CO2 emissions. Large scale implementation of green gas also increases security of supply. Green gas can be injected into the natural gas grid and can be used for all the same applications where natural gas is currently used for. ("Green gas explained"). Green gas is primarily a suitable solution in the case historic buildings that have strict restrictions for any modifications (Gemeente Amsterdam, 2016).

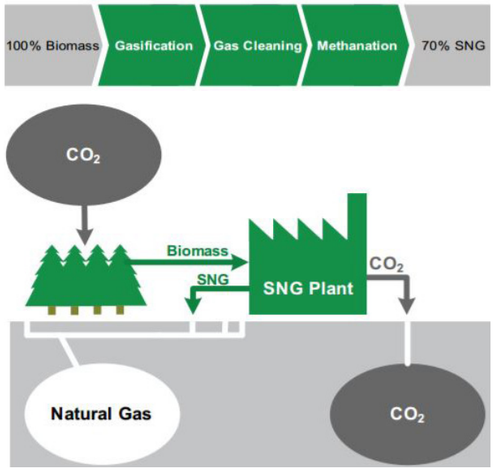


Fig. 9: Green gas system description (source: www.ecn.nl/fileadmin/ecn/units/bio/Leaflets/b-08-026_Green_Gas_explained.pdf)

Ground Source Heat Pump (GSHP)

GSHP (Ground Source Heat Pump) systems are closed loop systems in which ground heat exchangers are used in two types, vertical and horizontal systems. Vertical GSHP seem to be more convenient in the Netherlands because of the limited space. However, in large building plots horizontal systems are also possible. For vertical GSHP, the heat exchanger may be pressed into the ground or may be inserted into a drilled borehole. The depths of vertical boreholes usually lie between 20 and 250 meters. The average annual heat extraction is over 0.1 GJ/m2 (1000 GJ/ha) and cold extraction is 0.045 GJ/m2 (450 GJ/ha) ("Roadmap to nearly Zero Energy Buildings").

The energy efficiency of closed systems is on average a bit lower than in open systems. Closed systems are usually applied per house, but a collective system for an apartment building or multiple dwellings is possible. The depth and the number of boreholes can be defined by the capacity of the heat pump, soil type and available space ("Technieken: Ondiepe Bodemenergie - Gesloten Systemen | RVO.NI").

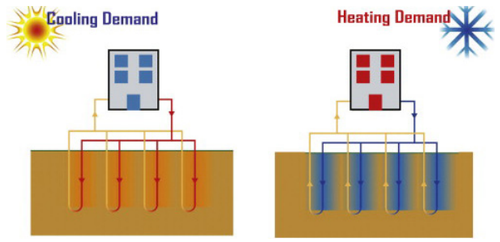


Fig. 10: GSHP system in Summer (left) - in Winter (right) (source: (Bloemendal, Olsthoorn and Boons 104-114)

Combined Heat and Power system (CHP)

Combined Heat and Power or Cogeneration heat and electricity are produced at the same time, creating a higher overall efficiency compared to separate production. "CHP plants generally have a steam turbine, and gas CHP plants have a gas turbine as well. The turbines produce electricity, and the excess heat can be provided to a district heating network. Combined cooling, heat and power (CCHP) plants have an absorption chiller that can use heat to produce cooling for district cooling systems"(UNEP, 2017). It should be noted that CHP is only sustainable when solid biomass or green gas is used as a fuel.

CHP installations are interesting in cases of constant heat demand, where electricity can be utilized directly. The non-used amount of electricity returns back to the local grid, minimizing the losses compared to decentralized power plants. CHP systems can also be used as emergency power equipment and are often applied in utility buildings and healthcare institutions. In the Netherlands, these systems are repeatedly used in greenhouses because of the stable heat and electricity demand ("Roadmap to nearly Zero Energy Buildings").

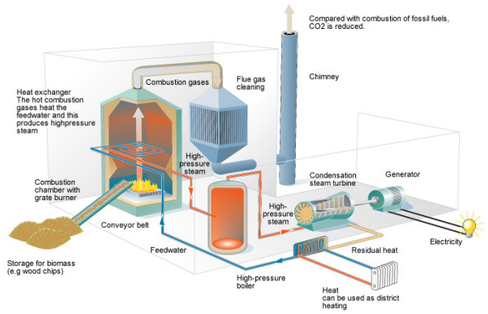


Fig. 11: Biomass-based CHP plant (source: http://alfa-img.com/show/plant-power-biomass-fuelled.html)

Deep geothermal system

Deep geothermal system operates with the extraction of hot water heated by the earth, which can then be used in district heating networks. Outside of the seasonal variations, the geothermal gradient of temperatures through the earth's crust is found about 30 °C per kilometre of depth in the Netherlands. The extraction heat site will be slowly cooled down over time, in the case that the heat extraction happens at a faster rate than the geothermal gradient can provide heat, and can lead to depletion in the long run ("Roadmap to nearly Zero Energy Buildings"). At shallow geothermal system a pit of about 2 kilometres depth is drilled, and deep geothermal system involves wells with a depth of about 6 kilometres. The heat from the shallow wells can provide with heat approximately 2,000 homes (4 MW), with deep wells around 20,000 dwellings (40 MW). The sources can be beaten near a heating network and connected so easily to it (Gemeente Amsterdam, 2016).

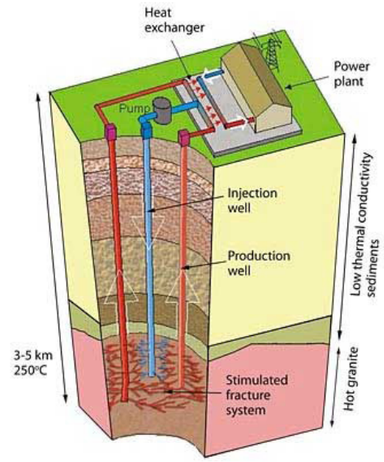
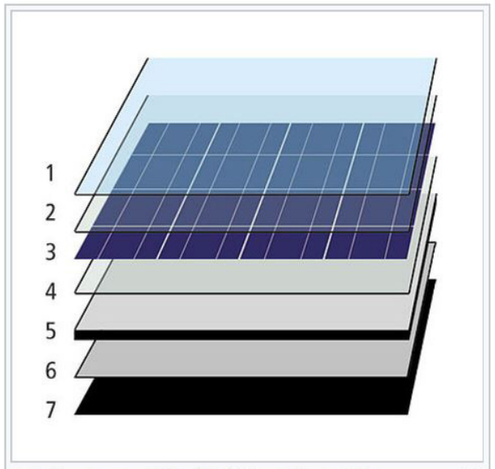


Fig. 12: Geothermal Energy Capture from Hot Rocks (source: http://www.mpoweruk.com/geothermal_energy.htm)

Photovoltaic thermal hybrid solar collector (PVT)

PVT panels are a combination of photovoltaic panels and thermal panels, with the thermal panels located on the back of the PV panel. The efficiency of a PV panel increases with decreasing temperatures. By using a thermal collector underneath the PV panel, the temperature of the PV panel is lowered, resulting in a higher electrical efficiency on the one hand, and in the availability of hot water on the other hand. This water can be buffered into a tank for later use. PVT panels are preferred to be installed on roofs and oriented to the south ("Photovoltaic Thermal Hybrid Solar Collector").



Schematic of a hybrid (PVT) solar collector:
1 - Anti-reflective glass
2 - EVA-encapsulant
3 - Solar PV cells
4 - EVA-encapsulant
5 - Backsheet (PVF)
6 - Heat exchanger (copper)
7 - Insulation (polyurethane)

Fig. 13: PVT panel description (source: https://en.wikipedia.org/wiki/Photovoltaic_thermal_hybrid_solar_collector)

Photovoltaic (PV)

PV technologies are mostly applied in the build environment, like modular PV panels that have an average efficiency of about 50%. They can also cover large areas in the city in order to create collective power plants and send electricity to the grid. Nowadays, building integrated techniques are becoming more available, on facades or creating shading systems. The retrofit of panels is also arising, since PV modules have a life cycle of at least 30 years. Sun tracking systems are under development as well, however, in most cases the panels are fixed on flat or tilt roofs ("Roadmap to nearly Zero Energy Buildings").

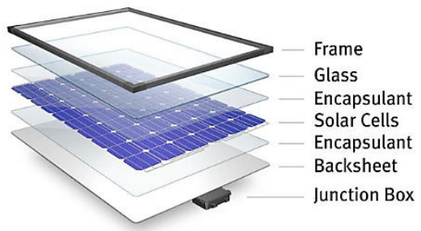


Fig. 14: PV panel description (source: http://www.dupont.com/products-and-services/solar-photovoltaic-materials/photovoltaic-backsheet-films/products/tedlar-film-based-backsheets.html)

Fig. 15: Solar photovoltaic panels field in Bavaria, Germany (source: https://en.wikipedia.org/wiki/Photovoltaic_thermal_hybrid_solar_collector)

Solar collector (SC)

The main functionality of solar collectors is to harvest radiation energy and transform it with a heat exchanger. Beside their use on individual building blocks, solar collectors can be sorted in fields for feeding the DHN with HT heat (UNEP, 2017). The ability of combining solar collectors with other heating and hot tap water systems is the reason that makes 'solar collector systems' attractive. Solar thermal roofs can be connected to a GSHP system with a heat exchanger, and with an ATES system combined with a heat exchanger as well ("Roadmap to nearly Zero Energy Buildings").

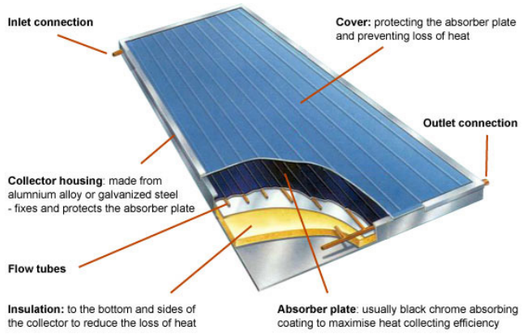


Fig. 16: Glazed flat plate SC description (source: https://www.designingbuildings.co.uk/wiki/Solar_thermal_systems)

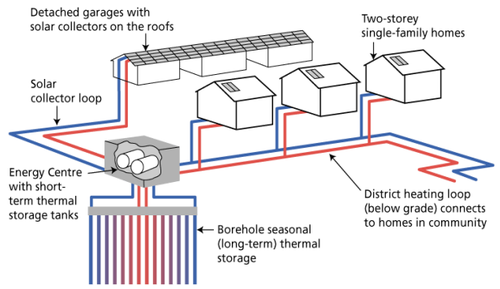


Fig. 17: District loop of solar collectors connected to borehole seasonal termal storage (source: http://solarconsultant.ca/2017/02/06/drake-landing-solar-community/)

2.5 RESIDENTIAL RETROFIT CASE STUDIES

Criteria for selection of case studies

The first limitations for selecting case studies are the use and the location of the buildings, since the project deals with the residential energy transition of Amsterdam Nieuw West. That means that they are all energy retrofit examples of residential areas in the same climate zone as Amsterdam. What needs to be identified from the case studies are the energy efficiency measures and the renewable energy technologies that are combined on different scales, referring to the retrofit of residential buildings and to the creations and extensions of the heat network on district scale. The case studies on building scale are analyzed based on the typology of the house, the building construction type, the envelope elements, and the technical installations of heating, hot tap water, ventilation and electricity production. On district and neighbourhood scales, the interest is on the extension of the existing heat network and on the creation of smaller heat networks in combination with renewable technologies

2.5.1 Oostland - From district to city

Description

The first case study of Oostland, concerns an existing study of energy transition in district scale, while scale as well, and follows the principles of City-zen project (Broersma & Fremouw, 2015). Oostland is a dutch region near Rotterdam, for which an energy urban study was made in order to collect data for the local energy demands and potentials, and give suitable energy solutions for the improvement of the local energy system. Following this process, an energy transition plan was proposed for the city of Pijnacker (Van den Dobbelsteen et al., 2014).

Basic principles

The energy transition plan starts from identifying the demands and potentials through Energy Potential Mapping (EPM). The proposed solution refers to a district heating network, that is connected with small scale heat networks to provide with heat sufficiently smaller parts of the district, and the heat is supplied from technologies utilizing local sustainable sources. The Small-scale heat networks represent the concept of energy cascade based on the function and construction specific heat demands. Figure 18, illustrates a geothermal heat source sends heat to a new built neighbourhood, that goes to an old neighbourhood and to innovative greenhouses before returning to the source as the temperature lowers.

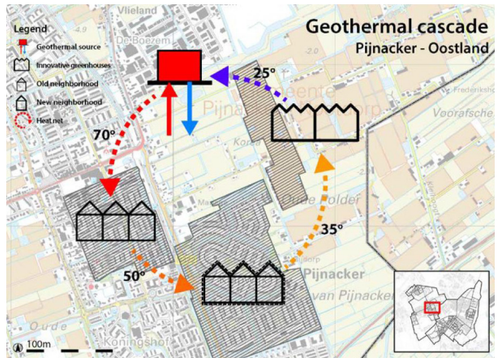


Fig. 18: Proposal of a geothermal cascade that consecutively supplies and older and newer residential area and a well- performing greenhouse area based on and quantified by the energy potential maps (source: Broersma et al., 2013b)

Steps

Initially, the energy demands and potentials of the area are identified, as already mentioned, and in figure 19, there is an example for the average per neighbourhood heat demand of the households and deep geothermal heat potentials (Van den Dobbelsteen et al., 2014). Afterwards, the plan is to create small heat networks serving parts of the city with high energy demands. Some potentially suitable renewable sources are planned to be connected to these smaller networks in order to supply them with heat. Afterwards, a main district heat network will be created, where the smaller networks will be connected to in the future. Also, the small-scale networks deliver heat both to the new neighbourhoods with well insulated residential buildings, and to the old neighbourhoods where retrofit measures need also to be applied. The Oostland study is a good example of the energy transition process of a district in steps, even though they are not defined on a timeline (figure 20).

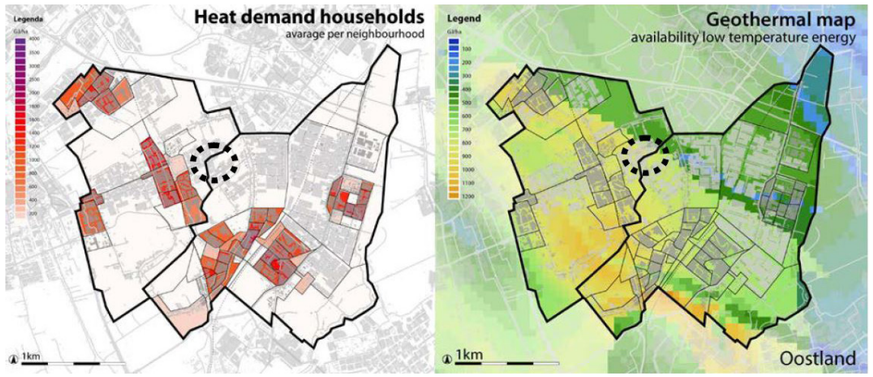


Fig. 19: Energy potential maps of heat demand of households in Oostland (left) and of deep geothermal wells (right) (source: Broersma et al., 2013b)

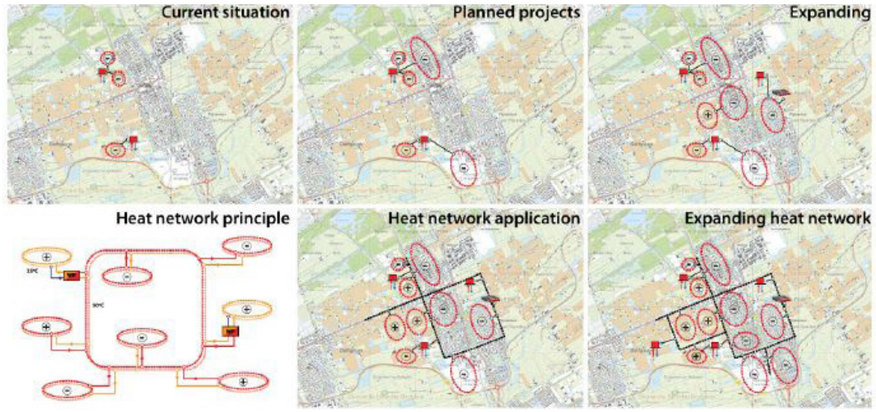


Fig. 20: Concept for an organically expanding district heating infrastructure for a self-sufficient Pijnacker (source: Broersma, 2014)

Energy and retrofit measures

In figure 21, the concepts of applying different renewable energy technologies based on local potentials, on the Small-scale heat networks are illustrated. The application of energy saving measures is not shown in the figures but they are considered anyway in the cases of retrofitted neighbourhoods. There are several concepts for old neighbourhoods. In the first one, the heat network is connected to a heat pump that is combined with heat and cold storage. In another concept the heat pump is connected to closed greenhouse where the heat exchanges, and to a heat and cold storage. There is a case that the heat pump is connected to solar heat collectors in asphalt and again to heat and cold storage, and a case that the heat network is connected to combined heat and power for the supply of heat and electricity to the old neighbourhood. Regarding new neighbourhoods there is a concept of connecting the heat network to geothermal heat exchange.

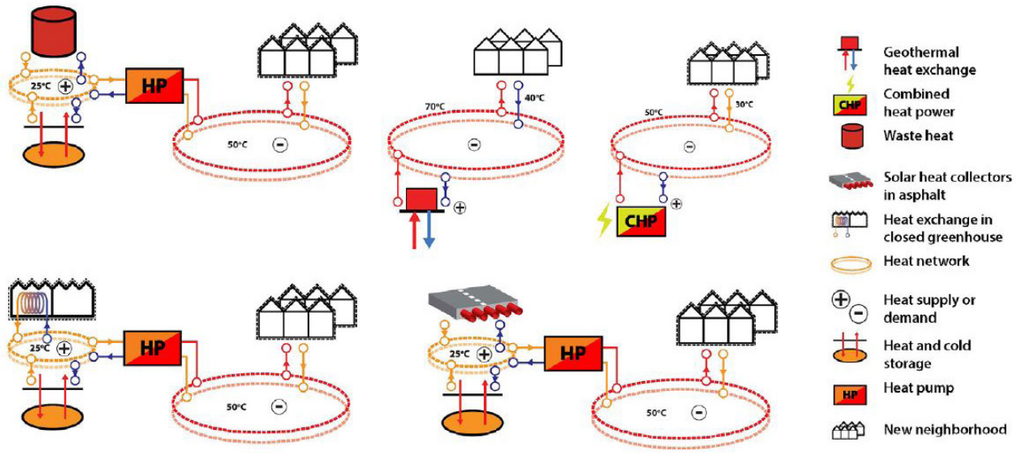


Fig. 21: Energy concepts for small scale heat networks on local potentials (source: Broersma, 2014)

2.5.2 Wijk van Morgen, Kerkrade - from building to neighbourhood

Description

This project includes 153 social-rental houses of which the 70 are double-storey apartments and the 83 are single-family houses. This complex of residential buildings is located in Kerkrade city near Maastricht and it was built in 1974. All dwellings have been refurbished in one year, starting from June 2012 and finishing at June 2013. The main construction is consisted of load-bearing brick walls and concrete slab floors. The duration of the refurbishment should be 8 working days because it was decided that the residents should stay inside through the process. Therefore, the interventions were made on the external surfaces of the buildings. The facades were out of two wooden elements and the windows of single panes. The envelope was not insulated and the dwellings had a gas fired central individual heating system (Mørck et al., 2014).

Basic principles

The basic principle of this case study was to achieve the Passive House standard, and the exploitation of solar energy has also a main role. The renovation concept should be repeatable under the purpose of the energy upgrade of a whole neighbourhood.

Energy and retrofit measures

First of all, the facades and roofs were fully replaced by prefabricated elements. Also, the roof panels were integrated with solar PV and thermal systems. The dwellings now have balanced mechanical ventilation with high efficiency heat recovery. Finally, a high efficiency condensing boiler and the solar thermal collectors provide the houses with heating and domestic hot water.

Fig. 22: Building after retrofit (right) and before retrofit (left) (source: Mørck et al., 2014)

Fig. 23: Diagrammatic top view of the area of retrofit(source: Mørck et al., 2014)

2.5.3 Retrofit case study in Trumpington, Cambridge - from building to district

Description

The described case study represents a competition entry in Cambridge named "Retrofit for the Future". The main research aim is about discovering what retrofit and energy measures offer the ability for upgrading the energy performance rating of existing social houses to label "A", and rapidly reduce the CO2 emissions. The chosen housing type is named as BISF, as British Steel Association, and is constructed from prefabricated steel building elements. The specific selected house is located in Trumpington, in the city of Cambridge, built in 1947, and there is a mass of the same houses built in the same period after the was in UK. The envelope has metal sheet claddings on the walls and a pitched DECRS roof. The roof was refurbished in 2001. The windows were replaced in 1997 with PVCu double glazing, and the heating system that was installed in 2009 is Vaillant Ecotec Plus 831 Gas Condensing Combi boiler. The retrofit team is composed of PRP Architects, Hill Partnerships, Cambridge City Council, Department of Architecture of the Cambridge University (Sunikka-Blank et al., 2012).

Basic principles

The development of a feasible and reproducible retrofit strategy for all dwellings that have the same type in the UK to achieve an "A" energy label.

Energy and retrofit measures

To achieve the goal of transforming the energy rating to "A", energy efficient building installations, as well as micro-renewables of energy were needed, to balance the energy consumption of the houses. For space heating, high-efficiency, low-emission balanced flue gas boiler with a flue gas heat recovery was used, to send heat to the existing radiators. Waste heat recovery units were placed to baths and showers. Also, a constantly working mechanical extract ventilation with a user-controlled boost was placed in the kitchen and the bathroom and trickle ventilators were located in the replaced windows. The lights in the building were replaced with LED lights and the kitchen equipment was replaced with "A++" energy-efficient white goods. Finally, for the use of renewable energy solar collectors and polycrystalline photovoltaic (PV) systems were installed.

Fig. 24: Building after retrofit (right) and before retrofit (left) (source: Sunikka-Blank et al., 2012)

2.6 ENERGY URBAN PLANNING METHODOLOGIES

2.6.1 Europe'S Buildings Under the microscope - BPIE model

This project occupies with the subject of the developing different scenarios aiming to make the building stock in Europe significantly more efficient, by following different renovation pathways in the period of 2010-2050.

These pathways are formulated mainly based on three variables. The first one is the rate of renovation, giving a ratio of the renovated building blocks per year leading to slow, medium, and fast rates. The second one is the depth of renovation, given in minor depth pursuing 30% energy savings by using 1-3 measures, moderate depth aiming at 60% savings with 3-5 measures, deep renovation at 90% by using a wholistic approach with a package of measures, and nZEB when renewable energy technologies are used for covering the remaining demand. The third variable is about the renovation cost which corresponds to the renovation depth.

A model was used to create scenarios with various speeds (slow, medium and fast) and depths of renovation (minor, moderate, deep and nearly zero energy), and all scenarios refer to one time building renovation between 2010 and 2050, beside the two-stage scenario which allows renovation interventions in two times during the same period. The results of the different scenarios vary regarding the CO2 emissions savings, however, the deep and two-stage scenarios have similar results, following the European CO2 reduction targets. In two-stage scenario, about half amount of money is needed for investment (Economidou, M. et al., 2011), concluding that retrofit in stages is more cost-effective.

2.6.2 From Trias Energetica to REAP methodology

Trias Energetica is a well-known sustainable energy approach that points at the energy transition of built areas, comprised of three steps regarding the reduction of the energy demand, the use of renewable energy sources and the use of fossil fuels efficiently.

Even though Trias Energetica strategy has been recognized as a logical and environmentally conscious approach, it seems that renewable sources have not been exploited as much as possible the last years, leading to the greater use of step 1 and step3. However, step 3 is the least sustainable solution, creating the need for reformulating this approach, to generate the New Stepped Strategy (Tillie et al., 2009). What differs in this strategy is the addition of a new step after step 1 of reducing the demands, and the removal of step 3 of using finite energy sources efficiently. Hence, the New Stepped Strategy is introduced in three steps that can be implemented on building level. These steps refer to the reduction of the energy consumption, the reuse of waste energy streams, and the use of renewable energy sources while ensuring that waste is reused as food.

REAP (Rotterdam Energy Approach and Planning) methodology exploits the principles of New Stepped Strategy by proposing the application of the steps on different scales, from building to neighbourhood, from neighbourhood to district, and from district to city. This approach pursues the optimal energy efficiency results, not only on building scale through individual attempts that do not interact with the surroundings, but also for the context of a whole city (Tillie et al., 2009).

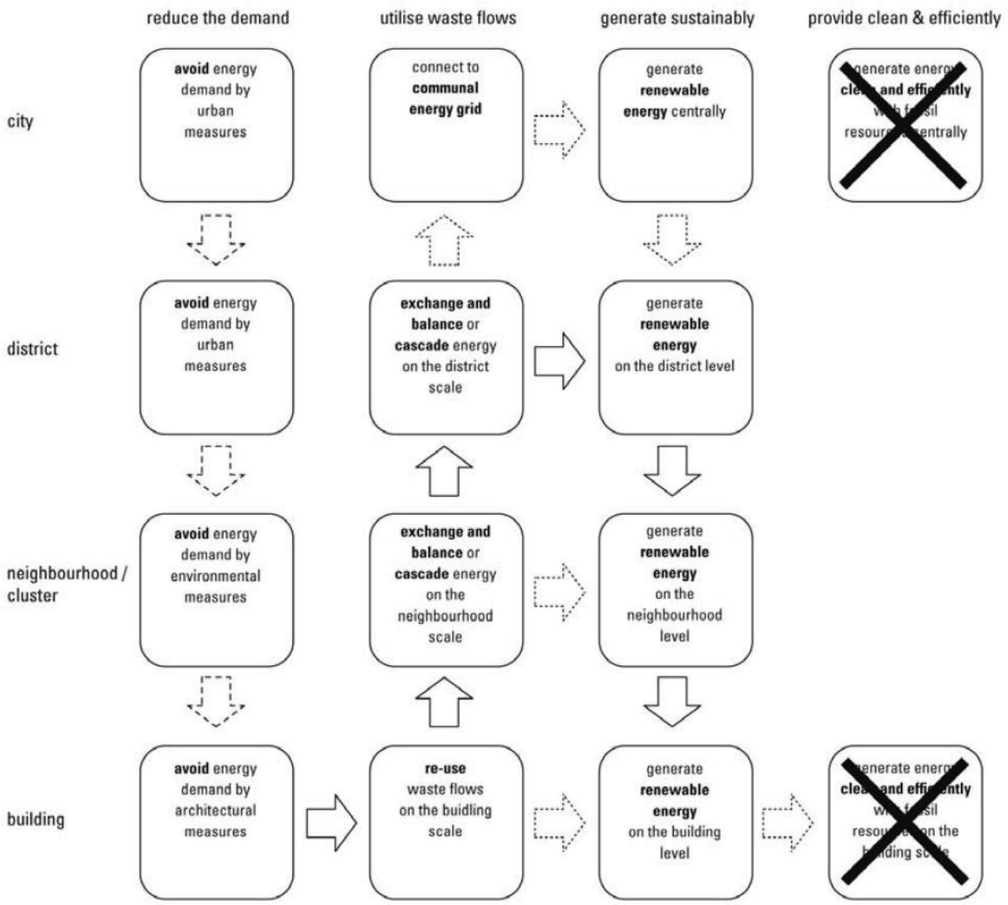


Fig. 25: The REAP methodology (source: Tillie et al., 2009)

2.6.3 City-Zen methodology steps

The main goal of City-Zen project is to develop a structured energy urban planning approach, pointing at the energy transition of cities, and for helping them achieve the EU energy goals of 2020 and beyond. Even through, several methodology steps are already defined to reach this objective, they are still under construction, and there is definitely room for testing and improvement.

At the present moment, six steps are defined by City-Zen approach. The first step is “map the present and near future”, which has to do with the collection of basic info and data on different levels of of the context. These levels concern the geographical-physical environment, the technical energy potentials through energy potential mapping, the financial barriers and opportunities, the social environment, the political environment, and the future and ongoing projects taking place in the city. The second step is to assume several possible future scenarios effecting the city, since the future cannot be predicted precisely, through local, national and international scenario studies. The third step concerns the collection and organisation of suitable measures in a catalogue, as well as the collection of case studies, offering inspiration for the measures’ on-site applications. Moreover, in step four, the energy targets and milestones are defined for the creation of a future scenario. Step five regards the roadmap design, where actions and strategies are determined to define suitable solutions on timeline, on technical and strategic level, and finally, step six has to do with re-calibrating and adjusting the already determined goals and milestones at set intervals, since the environment and actors can change over time (Broersma & Fremouw, 2015).

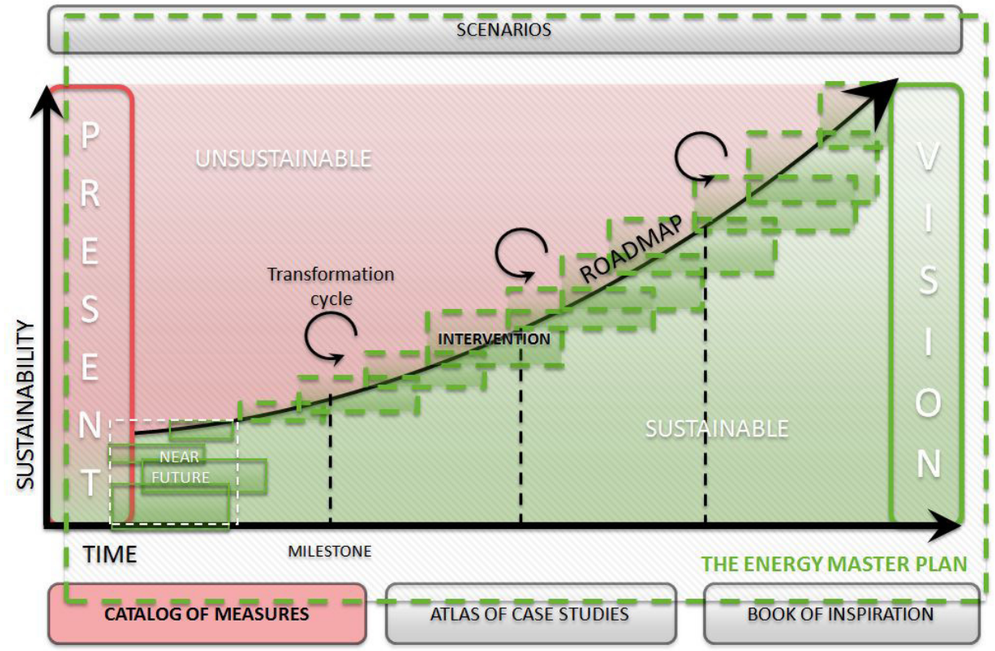


Fig. 26: City-zen approach framework (source: Broersma & Fremouw, 2015)

03

CONTEXT ANALYSIS

The present chapter is intended to give an idea of the energy conditions of Amsterdam city regarding the suitable alternatives of natural gas fuelled heat systems, as well as the current energy demand and potential maps. A second section presents an analysis of each dwelling for data extraction concerning the functions, the typology type, the energy consumption and the resulting CO2 emissions, that is conducted for selected neighbourhoods inside Amsterdam Nieuw West.

3.1 AMSTERDAM CITY

Based on the goal of Amsterdam municipality to turn Amsterdam city in a city with no gas and zero CO2 emissions until 2050 (Gemeente Amsterdam, 2016), different alternatives and a strategy for their implementation need to be figured out. According to studies conducted by Amsterdam municipality, there are already some attempts to develop a strategy serving the preservation of the heat supply in the built environment for the future gas-free Amsterdam.

3.1.1 Proposed energy systems & application scenarios for Amsterdam city

As described in these studies, the proposed alternative systems concern 1) turning existing houses to all-electric or NOM, 2) extending the DHN, 3) creating heat networks in smaller scale combined with heat and cold storage where heat comes from local sources like offices, supermarkets and datacentres, and 4) substituting natural gas with green gas (Gemeente Amsterdam, 2016). These four alternatives are studied further at later stage in order to find their on-site application requirements.

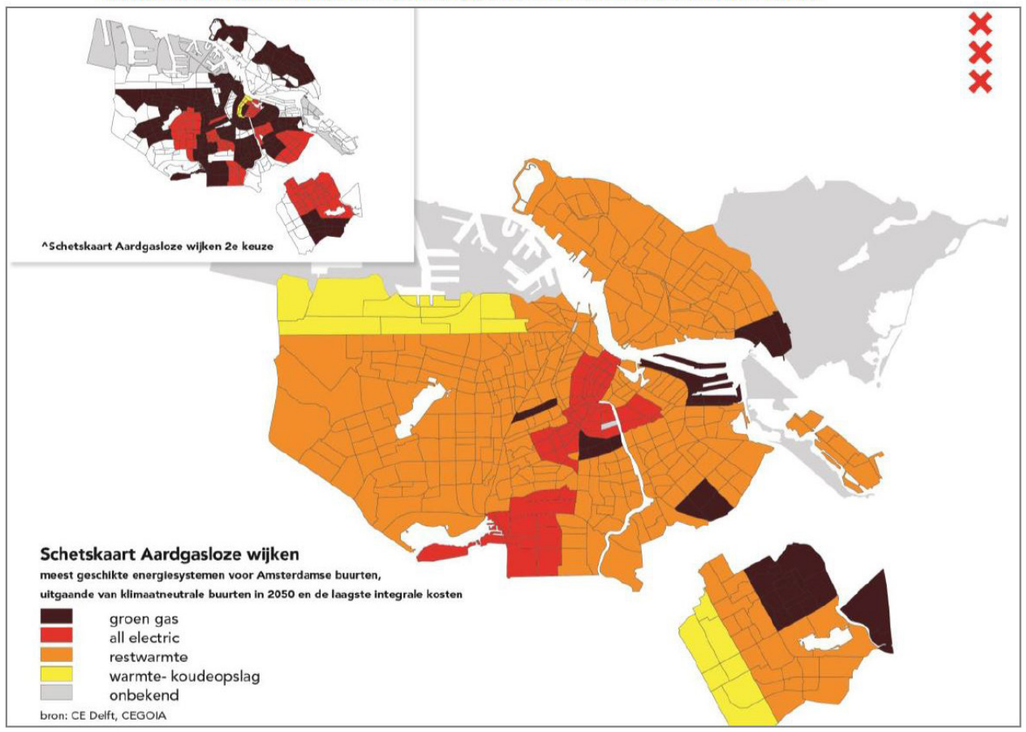


Fig. 31: Existing scenatrios of on-site energy systems applications (source: Gemeente Amsterdam, 2016)

There is always the possibility that different systems can be combined. The most suitable system or the most attractive source depends on territorial and building characteristics and varies from area to area. The most sufficient solution to reduce the energy demands and eliminate CO2 emissions in a city is when heat supply is combined with retrofit measures and the interventions include both city and building scale. In big cities, the best way to achieve a climate-neutral built environment is by using a large heat source. For the city of Amsterdam, DHN is an appropriate alternative to gas boilers in buildings and in parts of the city where there is no sufficient space for individual solutions. Also, it is the perfect solution in case that buildings have a high heat demand even after insulation. (Gemeente Amsterdam, 2016)

The configuration of solutions for the application of energy systems in different areas of Amsterdam is under research. Two of the existing proposals are shown in figure 31. Also, there is a proposal for the future extension plans of the DHN suggesting the extension of the grid to the Noord district of Amsterdam (figure 32).

The suggested energy systems application scenarios seem to be generalised and cannot represent the reality, as the suitable solutions can differ even on building level based on several variables that are going to be described later in sub-section 6.3.1. However, the mentioned systems are considered as the basic energy systems for applications on Amsterdam's neighbourhoods.

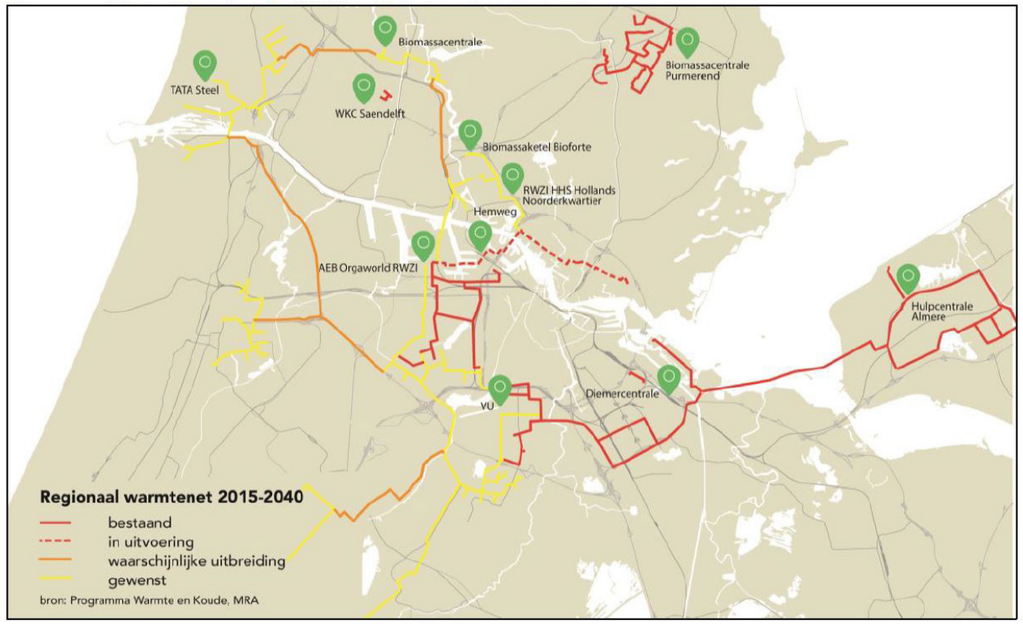


Fig. 32: Design MRA for possible future expansions of the regional DHN (source: Gemeente Amsterdam, 2016)

3.1.2 Collect energy demands

The current energy demands of natural gas and electricity for the whole city of Amsterdam, are identified during literature review, directly from the report with title Energy Atlas Amsterdam South-east (Geert den Boogert et al., 2014), where the demands are also mapped for each building block separately. The mapped average gas per m^2 and electricity per m^2 demands follow in figure 33 and 34 respectively. The electricity consumption reaches the value of 4,595,566,161 kWh/year and the gas consumption nowadays reaches the value of 788 716 193 m3/year. Since the energy potentials, presented in the next sub-section, are provided in PJ/year, the mentioned consumption values of gas and electricity are calculated as 16.5 and 27.7 PJ per year respectively (appendix).

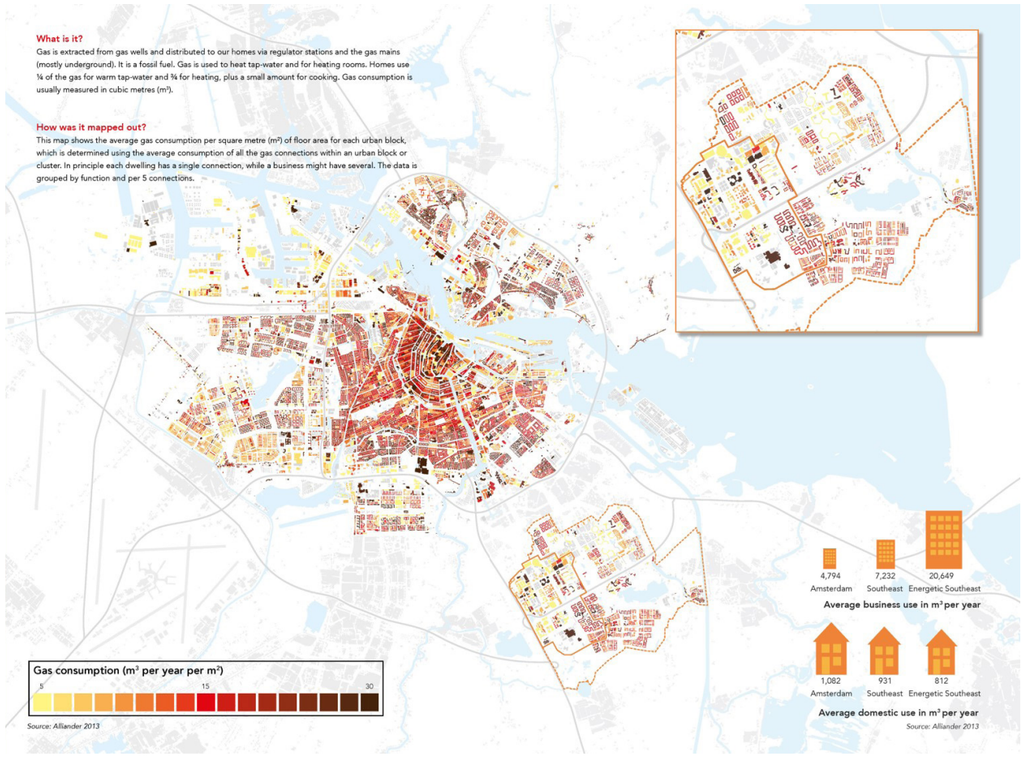


Fig. 33: Amsterdam map of the average gas consumption in m^3 per year per m2 (source: Geert den Boogert et al., 2014)

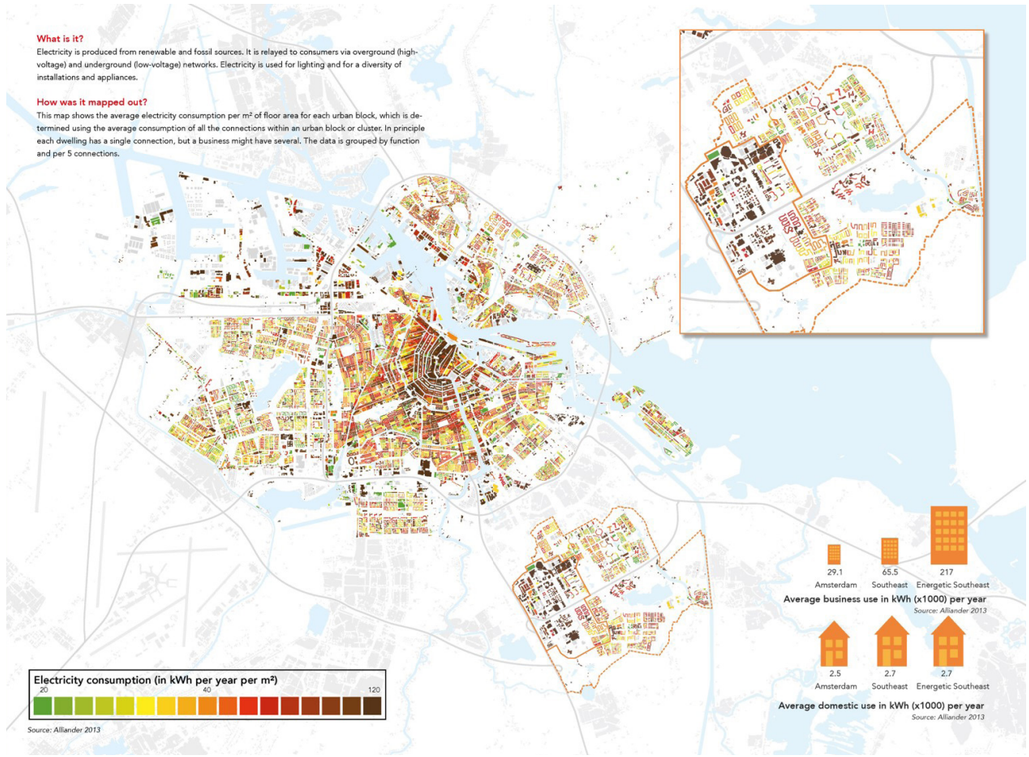


Fig. 34: Amsterdam map of the average electricity consumption in kWh per year per m2 (source: Geert den Boogert et al., 2014)

3.1.3 Collect energy potentials

Energy potentials offered from local renewable sources are also obtained from the same source as the energy demands where the amounts are already calculated (reference). In the process of context analysis, identifying the energy potentials is essential, since it is going to show whether the demands of gas and electricity can be fulfilled by renewables or not, and which sources correspond to the various heat systems. The energy potentials concern renewable sources like the sun, wind, water, geo, domestic waste, biomass and waste heat from buildings.

The quantified amounts from the different renewable sources are already quantified and represented on separate maps of Amsterdam. The example of the map of solar potential from PV panels on roofs (figure 35) follows to show that there is a distinguished value representing the total potential for Zuidoost district from the rest of Amsterdam. For this project, these values are added in all cases, in order to get an idea of the total potentials for the whole city, to be comparable in later stage with the total consumption values.

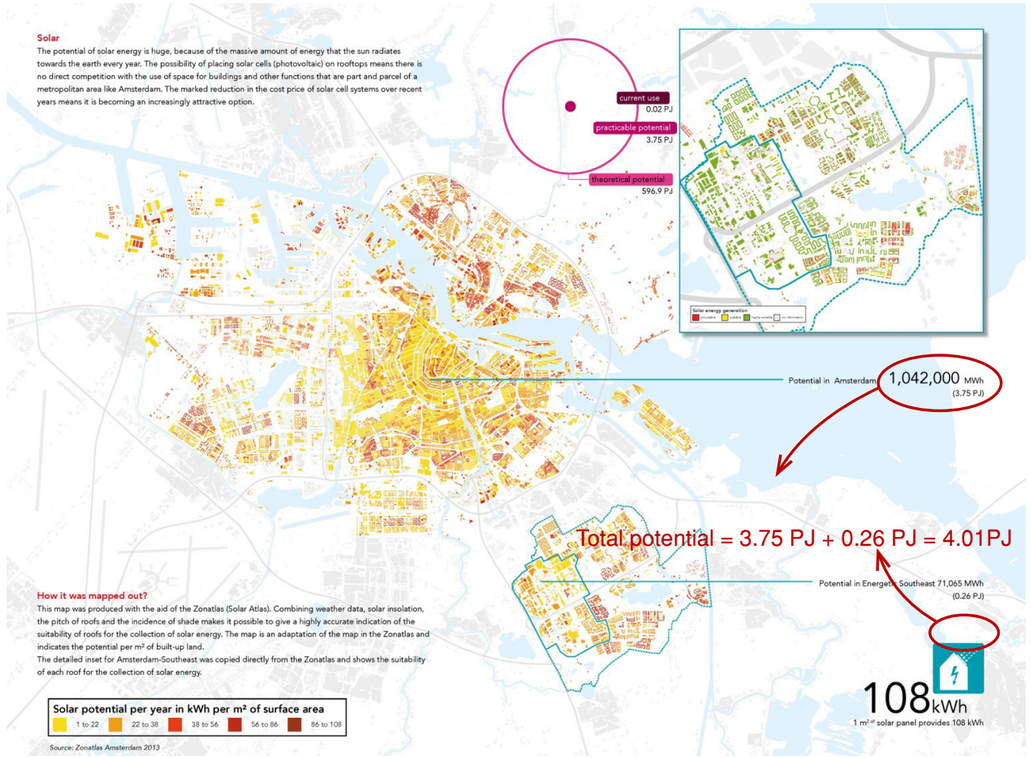


Fig. 35: Amsterdam map of the solar potential from PVs on roofs in kWh per year per m2 (source: Geert den Boogert et al., 2014)

All quantified values from local renewable energy sources (Geert den Boogert et al., 2014) are organised on table 4 aiming to give the current total energy potentials of the city. The renewable sources are illustrated in the first column, in second column the energy production technologies are mentioned right next to the maps representing the potentials throughout Amsterdam city, then the calculated values of total potential are illustrated, and last thing shown is if the energy produced is electricity or heat. The relation to electricity and heat is as referred to the source. Solar, wind, domestic waste, and biomass potentials are related only to electricity production, even though heat can be provided as well. For residual heat, soil and water, the quantified results express the energy produced for heating purposes.

The maximum solar potential can only be achieved for heat and electricity production if PVs, SC or PVTs are installed on all roofs. Electricity from large-scale wind turbines can also be provided to different areas through the city's network, and small wind turbines can be installed in individual cases. Domestic waste for waste incineration is expressed in 1.78 PJ, however, waste will be available in smaller amounts in the future because of recycling. Biomass seems to be available in a really small amount to support the heating of an area or of several neighbourhoods. Residual heat from non-residential buildings is possible to be used with low temperature small scale heat networks inside neighbourhoods. The ATES system offers space for 111.9 PJ, but other sources are needed to fulfill this space since it does not extract heat from earth. 8.4 PJ of heat are available with the use of GSHP and 9.36 PJ are available with deep geothermal source.

SUN	PV panels on roofs	4.01 PJ	ELECTRICITY
WIND	Wind turbines	1.78 PJ	
DOMESTIC WASTE	Waste incineration	1.18 PJ	
BIOMASS	Biomass treatment	0.06 PJ	
RESIDUAL HEAT	Supermarkets, Offices, Hospitals, Datacenters	1.90 PJ	HEAT
EARTH	Open loop thermal energy storage - ATES system	111.9 PJ available	
EARTH	Closed loop thermal energy storage - GSHP system	8.40 PJ	
WATER	Deep geothermal system	9.36 PJ available	

Table 4: Energy potentials from renewable sources potentials & energy production technologies (source: Geert den Boogert et al., 2014)

3.2 AMSTERDAM NIEUW WEST NEIGHBOURHOODS

Continuing the process of context analysis, after presenting the energy conditions of the city scale we move on to the neighbourhood scale, and even to building scale for the collection of data, since the aim of the project regards the energy transition of neighbourhoods inside Amsterdam Nieuw West. It is important to start from city scale before giving solutions of energy retrofit for neighbourhoods, as the energy amounts provided from the city's networks should not be avoided.

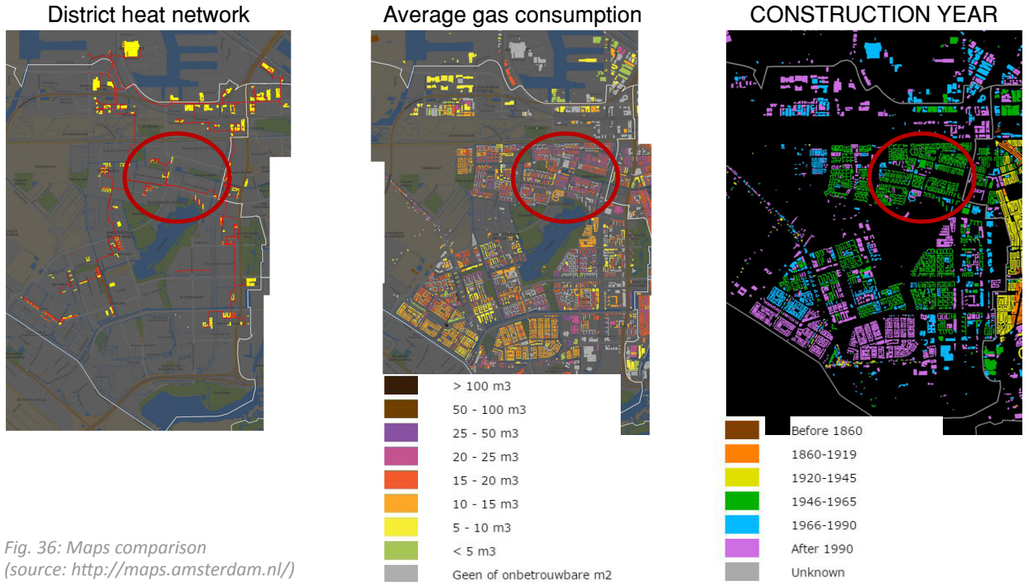


Fig. 36: Maps comparison (source: http://maps.amsterdam.nl/)

3.2.1 Site determination inside Amsterdam Nieuw West

Due to the time limit for this project, proposing retrofit intervention for the whole district of Amsterdam Nieuw-West did not seem to be an achievable goal. For deciding which part of the district would be the area of interest, the maps of the existing DHN, of the current average gas consumption in m3 per m2 per year, and of the construction year are compared (figure 36).

This comparison shows that an interesting area for intervention inside Amsterdam Nieuw West, that includes the Slotermeer-Zuidwest and Slotermeer-Noordoost combinations of neighbourhoods, because they seem to have a high concentrated heat demand, the construction year of the dwellings' majority is between 1946 and 1965, indicating that there is a certain need for insulation for the existing typologies (Konstantinou, 2014). An extraction of data concerning the description and the energy demands of each dwelling is described in the following sub-section.

Fig. 37: Selected neighbourhood combinations

3.2.2 Collect energy demands & typologies description data

A data extraction process was conducted aiming at the collection of information about the existing typology and the energy consumption, crucial for deciding which systems are suitable for each neighbourhood in later stage. A separate list for each neighbourhood contains data for each building block concerning the function, the typology, the construction year, the energy demands and the resulted CO2 emissions (Appendix). Also, the heat demand of each building was calculated as 90% of gas consumption (gas boilers of 90% efficiency are used), and the addition of heat demands of all buildings resulted the demand of the whole neighbourhood. Nonetheless, a more thorough inspection regarding the exact efficiency of gas boilers is required for the sake of achieving more accurate results of heat demand.

By knowing the use surface of each building in m2 (Haan) the average heat demand per m2 is calculated in a separated column of the template. The heat demand is significant for the application of the roadmap since the roadmap refers to the optimisation of the energy need for heating space and for DHW. The following table constitutes an example of all data collected in such list for four buildings inside Buurt 4 Oost.

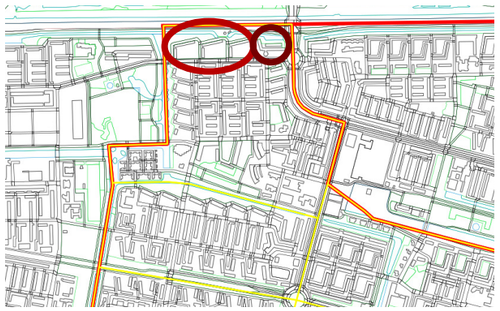


Fig. 38: Specific buildings data extraction

Area	Neighbourhood	Building block number	House typology	Additional classification	Year of construction	Storeys number	Type of roof	Electricity consumption kWh
Slotermeer-Zuidwest	Buurt 4 Oost	18937	Appartment bloc	Portiekflat	1955	5	sloped	93075
		18938	Appartment bloc	Portiekflat	1955	5	sloped	90100
		18939	Appartment bloc	Portiekflat	1955	5	sloped	122748
		190671	Appartment bloc	Gallerijflat	1959	9	flat	290376

Use surface m2	Electricity kWh/m2	Gas consumption m3	Gas m3/m2	Gas CO2 emmisions kg	Gas consumption kWh	Heat demand kWh	Heat demand kWh/m2
2804	33	59808	21	106458	584264	525838	188
2804	32	55056	20	98000	537842	484058	173
2804	44	58703	21	104491	573470	516123	184
6498	45	146382	23	260560	1430006	1287005	198

Table 5: Data extraction table (maps.amsterdam.nl)

3.2.3 Energy potentials

Another important factor that can determine the suitable local heat systems' applications, is the available local energy potentials in neighbourhood and building scale, also identified from the online source of maps.amsterdam.nl. Several local energy potentials maps are provided in figure 39, for the selected neighbourhoods.

In the figure below, the energy potentials from soil and water are illustrated corresponding to different energy systems. The ATES and GSHP are more possible for small scale applications (neighbourhood and building scale), and Deep geothermal system is most suitable for large scale application since it can provide the DHN with HT heat. The DHN is also shown with the buildings already connected to it, concluding that there is a good potential for more dwellings in the neighbourhood to be connected to it as well. Below, the map of the current potential household waste provided for waste incineration is demonstrated. However, the amount of waste is expected to be dramatically reduced until 2050, as recycling is increasing through the years. Finally, the potential residual heat from non-residential buildings is significant for the option of using LT small scale heat network in a neighbourhood.

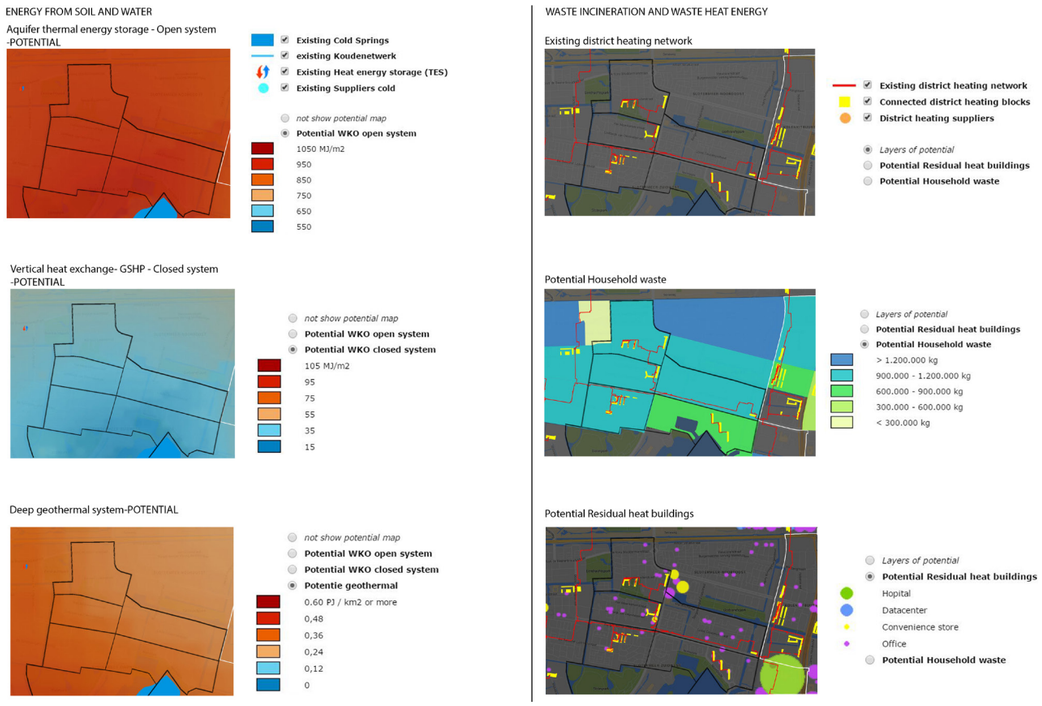


Fig. 39: Local renewable energy potentials maps (source: maps.amsterdam.nl)

04

ENERGY URBAN PLANNING METHODOLOGY

The current section explains the energy urban planning methodology leading to the design of a roadmap, to form decisions regarding the energy transition of residential neighbourhoods in Amsterdam Nieuw West. This methodology consists of two main sections, the catalogue of measures and the energy urban planning stepped methodology, both of them based on literature review. The catalogue offers retrofit solutions that will answer the variables of the roadmap, which results the final step of the stepped methodology.

4.1 ORGANIZING THE MEASURES IN A CATALOGUE

The research conducted on energy systems, retrofit measures and case studies regarding their on-site applications, contributes in the definition of a catalogue of measures, influenced by the principles of REAP methodology of reducing, reusing and producing energy, starting from city scale to scaling down to building scale (sub-section 2.6.2). Energy reduction, reuse and production measures are both useful for achieving the energy balance on different scales. Under the future goal for the reduction and even the elimination of CO2 emissions, for the production of energy for satisfying the remaining energy demand, renewable sources should be used for covering the needs for heating space, domestic hot water and electricity (figure 40). Cooling is not considered as a significant need for residential use in the climate of Netherlands.

Thus, the following catalogue of measures is organised according to the measures' energy characteristics (reduce, reuse or produce), and their application scale (building, neighbourhood, district). This catalogue is useful at the stage of the roadmap decision-making, to define on-site energy retrofit solutions inside each neighbourhood (table 6).

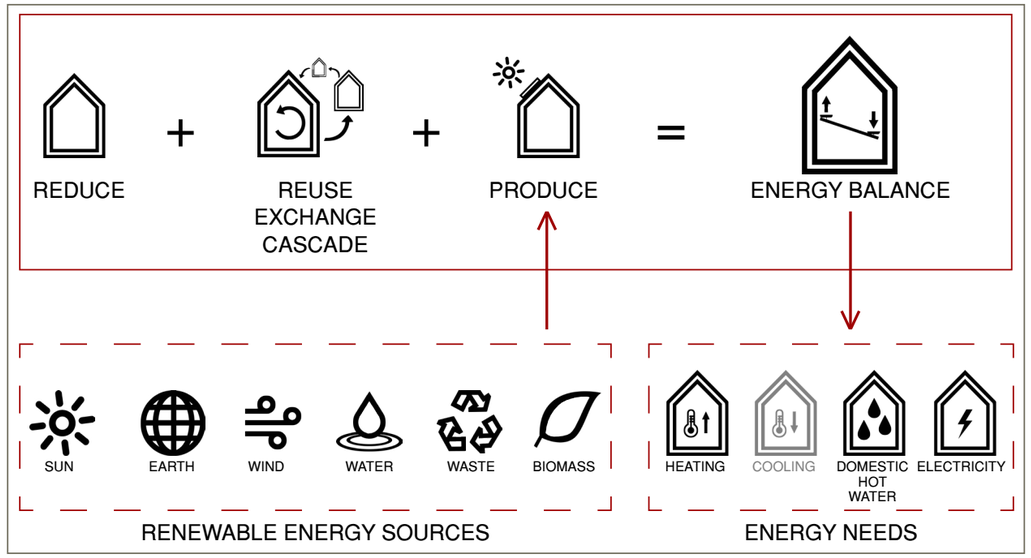


Fig. 40: Basis of categorizing

	BUILDING	NEIGHCOURHOOD	DISTRICT
ENERGY SAVING MEASURES			
Exterior walls insulation	✓		
Roof insulation	✓		
Ground floor/basement ceiling/basement wall insulation	✓		
High-performance windows	✓		
Energy efficient lighting	✓		
Shading systems - Solar protection	✓		
Efficient mechanical ventilation system (with heat recovery)	✓		
Shower heat exchangers	✓		
ENERGY EXCHANGE MEASURES			
Waste heat from industrial units			✓
Waste heat recovery for building heating	✓		
Energy exchange between building zones	✓		
Energy exchange between buildings		✓	
Energy cascade		✓	
Smart appliances (dishwasher, clothes washer & dryer, Refrigerator, water heater)	✓		
RENEWABLE ENERGY TECHNOLOGIES			
Photovoltaic's (PVs)	✓	✓	
Solar Collectors (SC)	✓	✓	✓
Photo Voltaic Thermal systems (PVT's)	✓		
Heat pumps (ground source, air, water or waste heat)	✓	✓	✓
Deep Geothermal systems			✓
Aquifer Thermal Energy Storage (ATES)	✓	✓	
Road collectors with ATES	✓	✓	
Waste-to-energy district heating plant			✓
District heating boiler fuelled by electricity, biogas, wood pellets, wood chips (usually as backup heating systems)			✓
Combined Heat and Power (CHP) system fuelled by biogas or biomass			✓
Wind turbines	✓		✓

Table 6: Catalogue of measures for this project

4.2 DEFINING ENERGY URBAN PLANNING METHODOLOGY STEPS

In this section, after an overview of existing energy urban planning methodologies, and mainly influenced by the City-Zen methodology steps (recall sub-section 2.6.3) and the REAP methodology suggesting energy transition interventions from city scale to building scale, a 4-step energy urban planning methodology is developed. City-Zen methodology is consisted of 7 steps, from which step 1, step 4, step 5 and step 6 of "map the present", "define desired future", "select energy systems" and "roadmap design" respectively, are exploited for developing another stepped methodology. For this project, the methodology steps formulated as mapping the present, defining the future energy targets, developing strategy for selecting suitable energy systems, and finally getting to the desired roadmap design, must be followed in this order, aiming the energy transition of residential neighbourhoods.

In order to get to the final result of the roadmap design for the selected residential neighbourhoods of Amsterdam Nieuw West, the application process should start from the city scale, to get gradually to the neighbourhood scale. Applying the first 3 steps on big scale initially, is significant for giving an idea of how much energy is offered from city's energy potentials to Amsterdam Nieuw West district, of whether the potentials can possibly cover the demands in general by available renewable sources, and of which are the consequent corresponding energy systems for local neighbourhoods. Afterwards, the stepped methodology indicates to repeat the 3 steps for the selected neighbourhoods in Amsterdam Nieuw West that will guide to the 4th step of roadmap design for the selection of suitable energy systems for the neighbourhoods.

As shown in figure 41, several sub-steps are defined for the completion of each step, that differ at points between the two scales. Thus, a more detailed description of each step follows below, showing the process to follow from city to neighbourhood scale leading to the desired energy retrofit results.

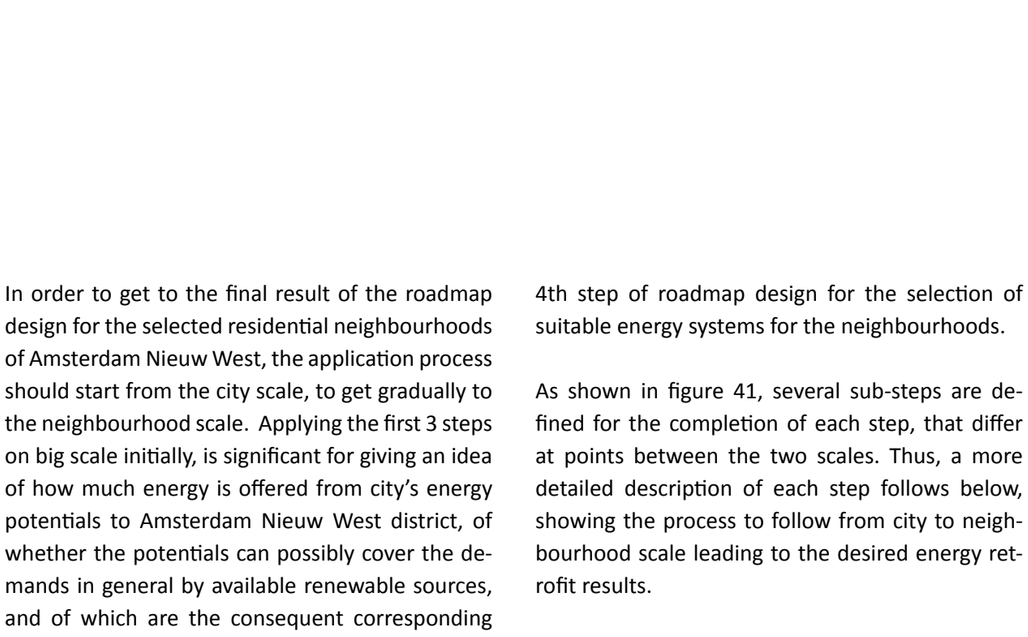
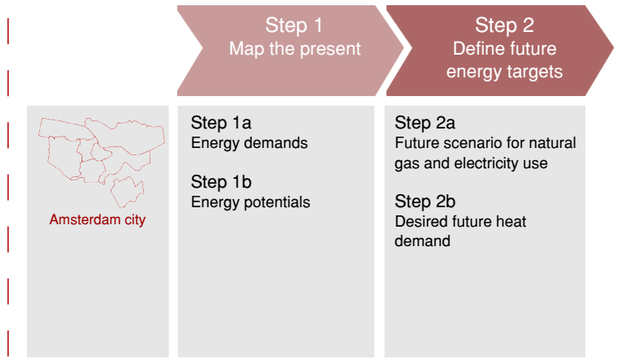
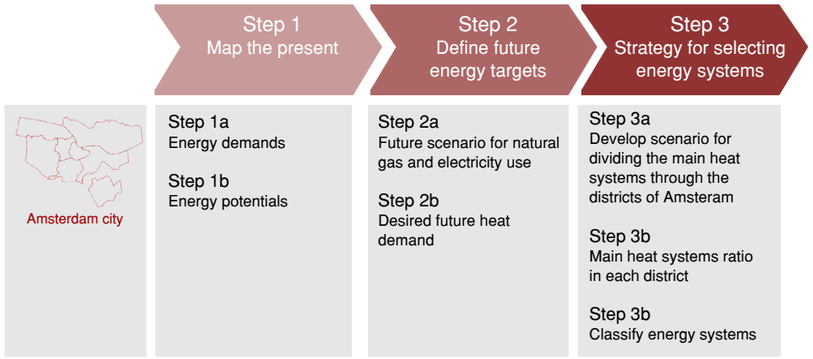


Fig. 41: Energy urban planning methodology steps

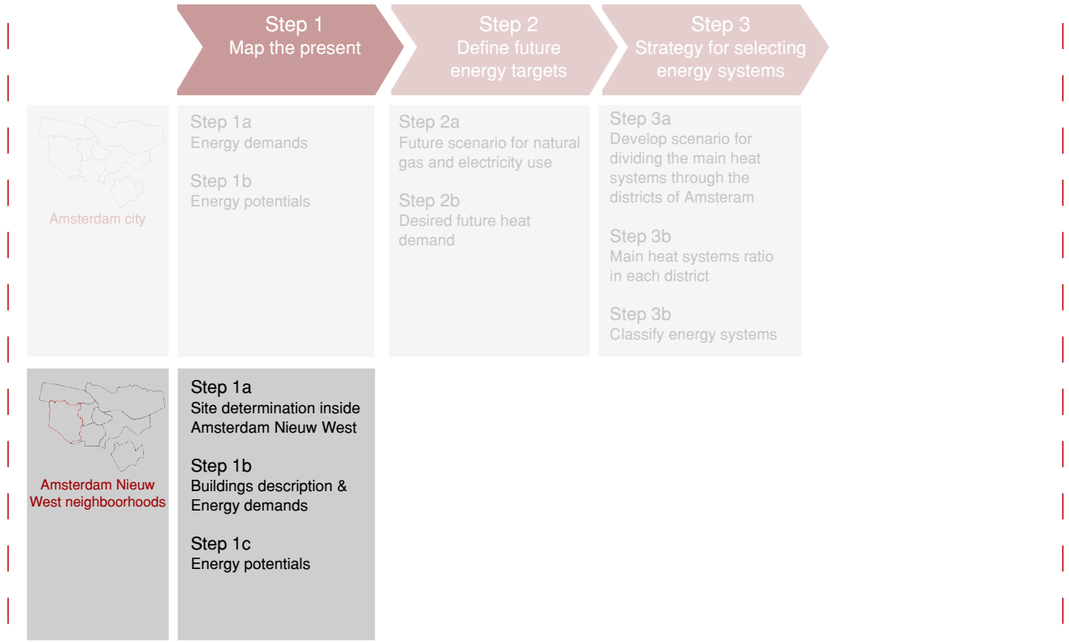
The first step of mapping the present includes two main sub-steps regarding the energy demands and energy potentials of the city. This step is basically done through the context analysis of the city for the collection of the relative data. The current energy demands refer to natural gas and electricity, and the current potentials refer to the available energy amounts from the renewable sources of sun, wind, earth, water, domestic waste, biomass and residual heat of non-residential buildings (recall section 3.1).



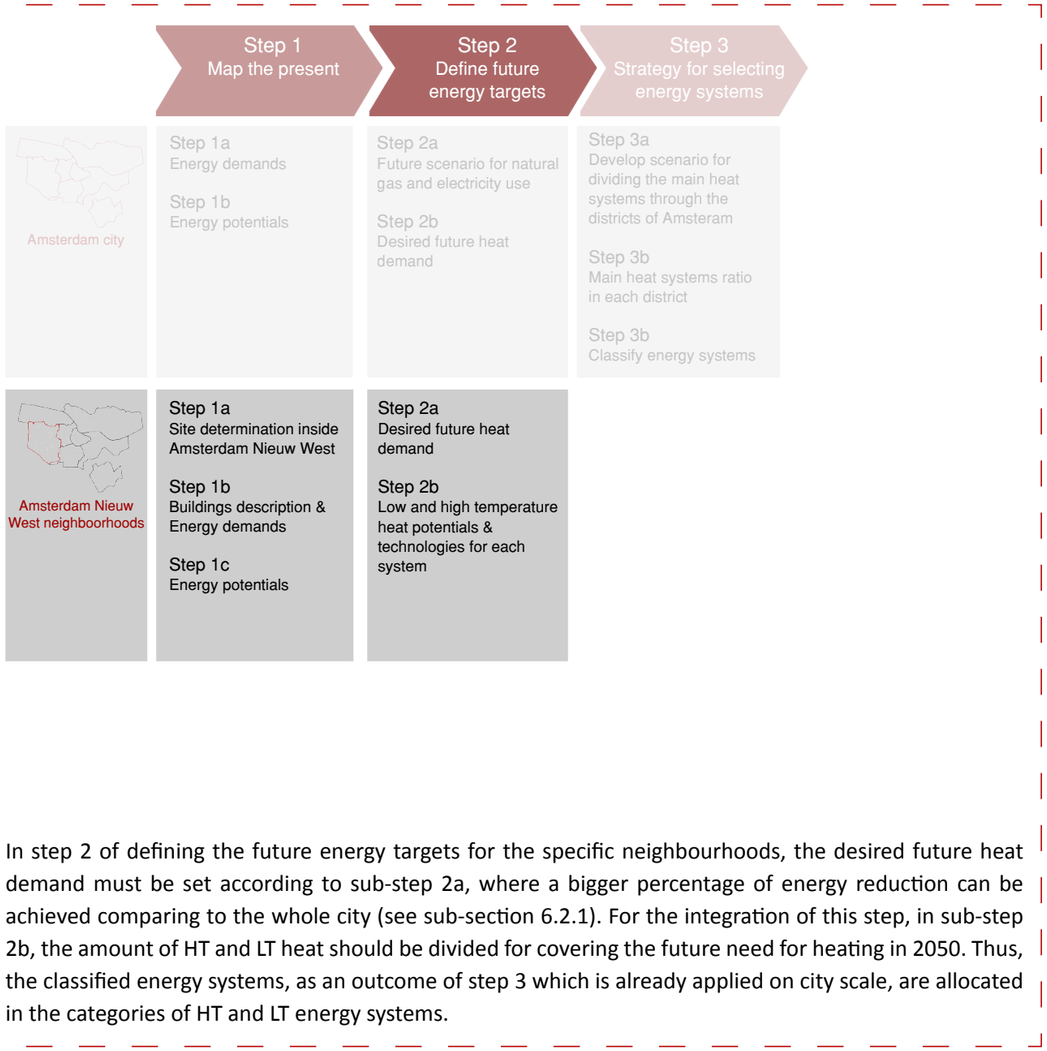
About the definition of future energy targets in step 2, the first sub-step is the creation of a scenario for the future use of natural gas and electricity. A target already set for this project, is the end of the use of natural gas until 2050. The final roadmap though, aims to give solutions for improving the energy performance for the heating needs of dwellings. The required need for heating will not be related in the future with the natural gas use. By setting a specific energy target for the heat demand in 2050, in the second sub-step, it is easier to find the means (develop strategies and select energy systems) to achieve it.



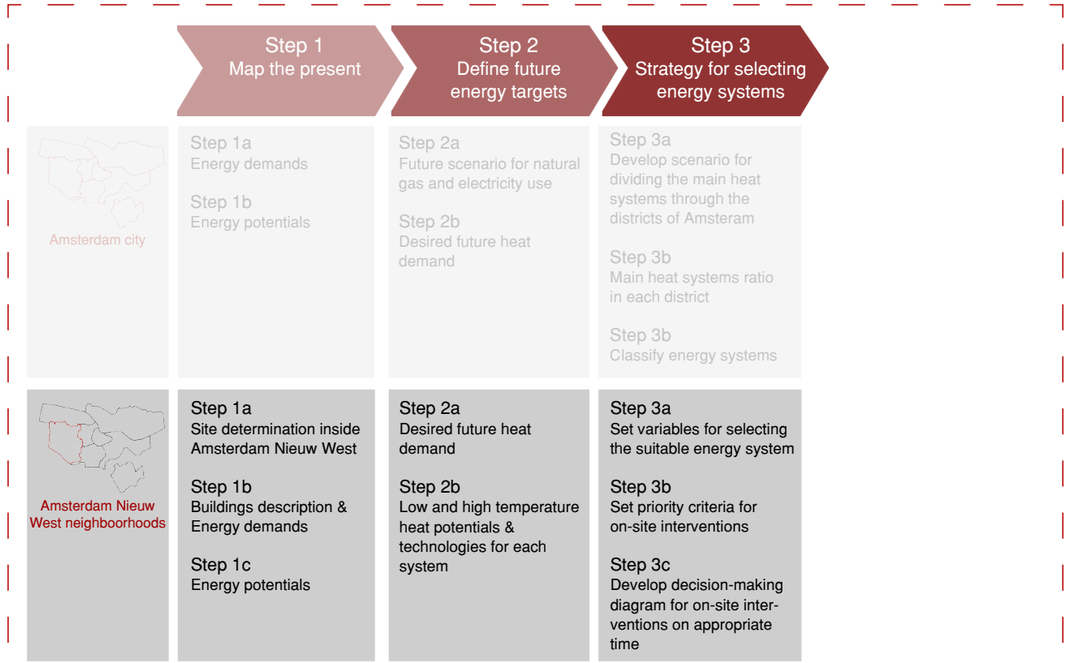
The next step concerns the strategy development for selecting energy systems for the districts of Amsterdam, which is comprised of 3 stages. It starts with the development of a scenario for dividing the main (LT and HT) heat systems through the districts of Amsterdam which is indicated by the available heat amounts from renewable sources. For the completion of this sub-step, the already defined 2050 heat demand is compared to the renewable sources potentials to conclude whether they can cover it. Then a logical assumption for the potentials of low and HT heat amounts percentages offered in 2050 is needed, to move on the second sub-step of defining the main heat systems ratio for each district. In last stage of this step, by knowing the energy potentials identified from step 1 of the methodology, the corresponding energy systems can be classified.



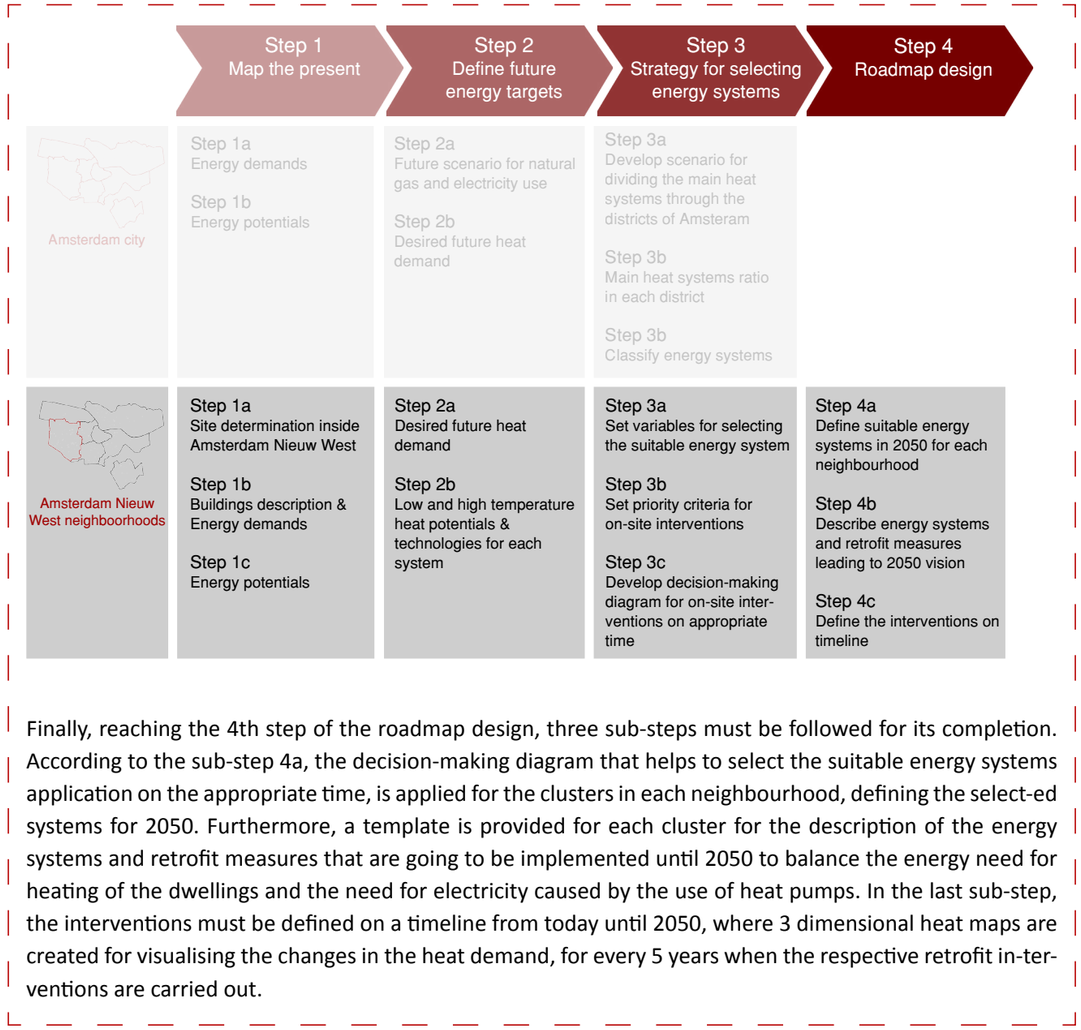
Continuing the process of the stepped methodology leading to the energy transition of neighbourhoods in Amsterdam Nieuw West district, the return back to step 1 is required, for selecting specific neighbourhoods for intervention in sub-step 1a, for collecting data about the existing typology description and the energy demands of each house in sub-step 1b, as well as about the local energy potentials in sub-step 1c. All this data is collected through context analysis, and the current heat demand of each building is calculated out of the natural gas demand (recall section 3.2).



In step 2 of defining the future energy targets for the specific neighbourhoods, the desired future heat demand must be set according to sub-step 2a, where a bigger percentage of energy reduction can be achieved comparing to the whole city (see sub-section 6.2.1). For the integration of this step, in sub-step 2b, the amount of HT and LT heat should be divided for covering the future need for heating in 2050. Thus, the classified energy systems, as an outcome of step 3 which is already applied on city scale, are allocated in the categories of HT and LT energy systems.



At this point of the stepped methodology, a strategy for selecting the suitable energy systems inside each neighbourhood is developed. The first stage of this strategy is to set variables for selecting suitable energy systems. These variables are determined by literature review regarding the application requirements of the energy systems. Also, priority criteria for on-site interventions are set in second stage, since the systems and the retrofit measures cannot be applied inside all neighbourhoods at once for practical and cost reasons. The combination of the two first stages lead to the development the third stage, of a decision-making diagram for on-site interventions on appropriate time. This diagram contributes in prioritising buildings for retrofit, and in categorising the dwellings of the same construction and ownership characteristics inside each neighbourhood in clusters, for giving the suitable retrofit solutions to the clusters consisting each neighbourhood.



Finally, reaching the 4th step of the roadmap design, three sub-steps must be followed for its completion. According to the sub-step 4a, the decision-making diagram that helps to select the suitable energy systems application on the appropriate time, is applied for the clusters in each neighbourhood, defining the select-ed systems for 2050. Furthermore, a template is provided for each cluster for the description of the energy systems and retrofit measures that are going to be implemented until 2050 to balance the energy need for heating of the dwellings and the need for electricity caused by the use of heat pumps. In the last sub-step, the interventions must be defined on a timeline from today until 2050, where 3 dimensional heat maps are created for visualising the changes in the heat demand, for every 5 years when the respective retrofit in-ter-ventions are carried out.

05

APPLICATION OF METHODOLOGY STEPS ON AMSTERDAM CITY

The results of implementing all energy urban planning methodology steps already described, are stated in the two following sub-sections. Solutions regarding the districts of Amsterdam come out of the steps application on city scale, before scaling down for applying the steps on neighbourhoods of Amsterdam Nieuw West.

5.1 MAP THE PRESENT

Starting from mapping the present for Amsterdam city, the collected data from the preceded context analysis are used in this step. The current energy demands of electricity and natural gas, as well as the energy potentials offered from each renewable local source are already known (Geert den Boogert et al., 2014). The results are mentioned in the following sub-sections. These data are crucial for developing a scenario for the heat demand of the city in 2050, that is necessary for the selection of energy systems subsequently.

5.1.1 Energy demands

The gas demand for the city of Amsterdam, as already mentioned is 788716193 m3/year and the electricity consumption is 4595566161 kWh/year in 2014 (Geert den Boogert et al., 2014). For this project, the consumption is assumed to be the same in 2017 since these are the most recent data found. By converting all units in Petajoules, the gas consumption is 27.7 PJ and the electricity consumption is 16.5 PJ, resulting in total energy consumption of 44.3 PJ in a year for the whole city of Amsterdam.

5.1.2 Energy potentials

The following numbers represent the maximum energy potentials from different energy technologies, covering all districts of Amsterdam city. As revealed from context analysis (recall sub-section 3.1.3), the energy potentials from PV panels, from large scale wind turbines, from domestic waste incineration, and from biomass treatment reach the values of 4.01 PJ, 1.78 PJ, 1.18 PJ and 0.06 PJ respectively for electricity production, leading to the total amount of 7.03 PJ of produced electricity.
Emphasising on heat production, the potentials come from rest heat from supermarkets, offices, hospitals, and datacentres, from GSHP system, from ATES system, and from deep geothermal system. Rest heat from non-residential building can offer 1.9 PJ, and GSHP system 8.4 PJ. Deep geothermal system can offer up to 9.36 PJ, and ATES system has available storage space for 111.9 PJ.
However, there are heat potentials from renewable sources not mentioned in the Energy Atlas of Amsterdam Southeast, that seems to occupy with certain solutions. In reality, more energy production technologies for heating exist, and can be utilised according to the available local renewable sources of Amsterdam. For generating a more integrated image, a stacked graph with the heat potentials is created, in order to compare it later (sub-section 5.3.1) with the current energy demands of the city. For the completion of this diagram, the heat potentials from solar collectors, PVT's, biomass treatment from heat produced by waste incineration are added. The ATES system is considered to be fulfilled by PVT's and the rest heat from non-residential buildings. Thus, the total value of current heat potentials is 31.3 PJ.

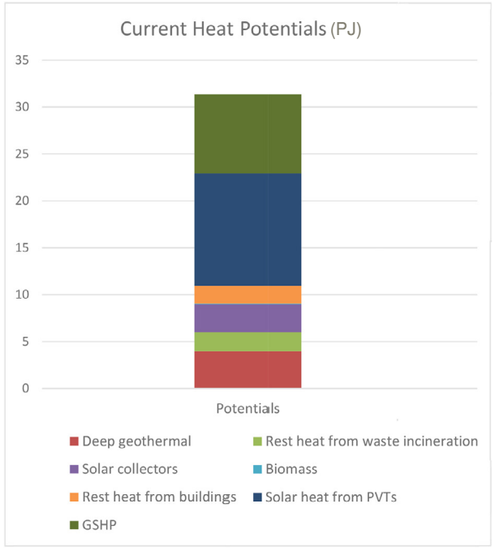


Fig. 42: Current heat potentials from local energy renewable sources

In the previous diagram, the current heat potentials produced by different technologies are represented. Starting with deep geothermal system, only 4 PJ are used in this project from the total potential of 9.36 PJ provided by this heat system, because it is not advisable to use all this potential in short period of time because 30 years is the period needed to substitute this energy amount (feedback from domain expert). 2PJ for the heat produced by waste incineration, and 3 PJ - 6 PJ by solar collectors are assumed as logical amounts for the whole of Amsterdam city (feedback from domain expert). The low availability of biomass is remarkable, as a total of 0.06 PJ for heat and electricity production, making doubtful whether the amount of produced green gas can support the heating of several residential neighbourhood combinations in Amsterdam. Thus, an assumption is that it green gas could be used in transport. The amount of rest heat from non-residential buildings and the from GSHP are retrieved directly from the Energy Atlas Amsterdam Southeast, as 1.9 PJ and 8.4 PJ respectively. Finally, according to domain expert, the ATES system can be filled up with 12 PJ from PVT's, and with 1.9 PJ from rest heat from non-residential buildings.

5.2 DEFINE ENERGY FUTURE TARGETS

As already mentioned this sub-section refers to the formulation of a future scenario concerning the natural gas and the electricity use, as well as for the future target regarding the heat demand of the city of Amsterdam. These scenarios are explained in the upcoming paragraphs.

5.2.1 Future scenario for natural gas and electricity use

The future intention for gas use is to reach zero in 2050 according to the goal of transforming Amsterdam into a gas-free city (Gemeente Amsterdam, 2016). As far as it concerns the electricity use in 2050, it is assumed to remain the same as today. This assumption is based on the fact that the demand reduction is possible when replacing the existing appliances with better performing and demand-responding ones, however, the need for electricity is increasing again for the operation of heat pumps installed with new LT heating systems. The scenario is illustrated on the graph below.

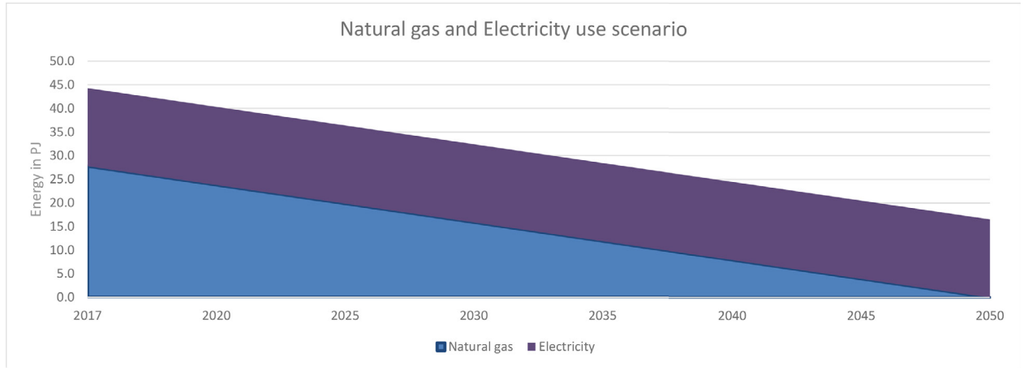


Fig. 43: Natural gas and electricity use scenario aiming to eliminate gas use until 2050

5.2.2 Desired heat demand

As a next step, the value expressing the natural gas demand is used to calculate the current heat demand that the roadmap deals with. By assuming that 90% efficiency boilers are used, the current energy demand for heating as 25 PJ out of 27.7 PJ of natural gas. A more thorough inspection regarding the exact efficiency of gas boilers is required for the sake of achieving more accurate results of heat demand. The rest 10% include gas used for cooking and the energy losses. This 90% include the gas used for heating space which is 70%, and for DHW which is 20%.

The percentage of heat reduction until 2050 is assumed as 60%, meaning that the demand for space heating will be reduced in a bigger percentage than for DHW, since the need for DHW remains the same through the years. A deeper analysis of the current heat demand, the current energy potentials and the future energy systems lead to the assumption of heat demand reduction (for heating space and DHW) by 60% in 2050. This analysis is going to be described in more detail in section 5.3.1 of developing the scenario for dividing the main heat systems through the districts of Amsterdam.

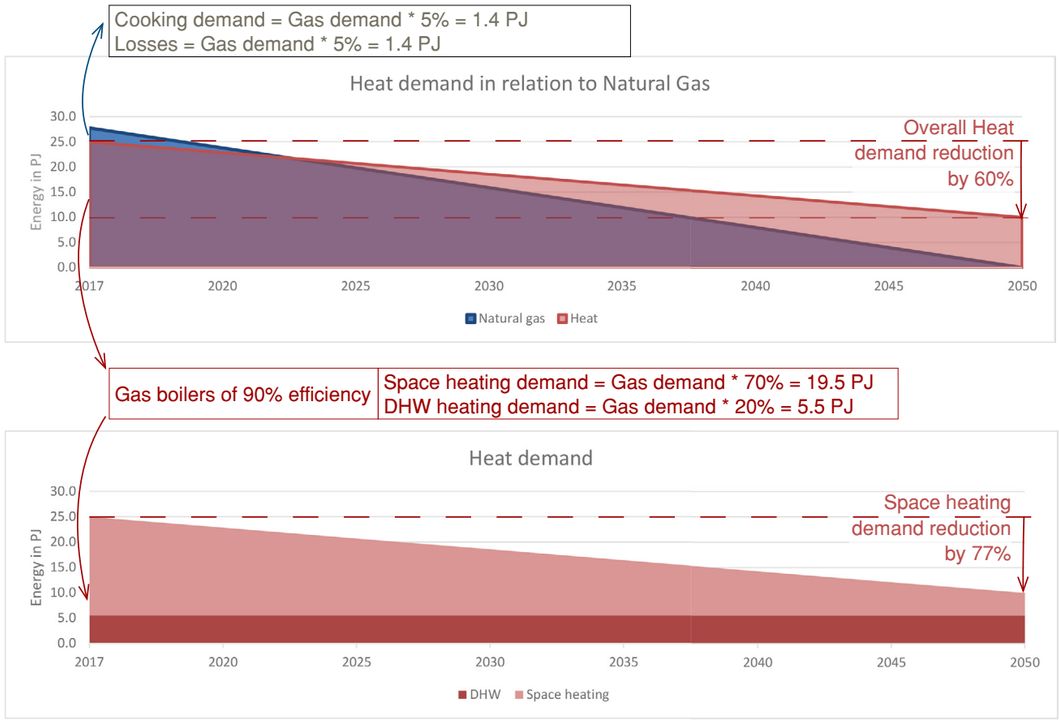


Fig. 44: Setting the goal for regarding the future heat demand

5.3 STRATEGY FOR SELECTING ENERGY SYSTEMS

The current section focuses on the development of a scenario in order to divide the main heat systems, providing the dwellings with high or low temperature through Amsterdam's districts. This scenario is essential for proposing the future ratio of the main heat systems inside each district and for classifying the possible energy systems to be implemented on neighbourhoods of Amsterdam Nieuw West afterwards.

5.3.1 Develop scenario for dividing the main heat systems through the districts of Amsterdam

The development of the scenario for dividing the main heat systems (LT and HT) through the districts of Amsterdam city, is comprised of several stages. First, the current heat potentials from renewable sources are compared to the current heat demand to examine whether they are promising for covering the heat demand. Secondly, the choice of considering a percentage of 60% reduction of heat demand until 2050 is justified, and the heat potentials are categorized as LT and HT, to figure out in what percentages they can fulfill the future demand. By assuming how much LT heat will be produced in 2050, the resulted electricity amount for heat pumps' operation can be found. At this point, the collected electricity potentials are useful to validate whether this electricity demand can be efficiently covered.

The following graph mainly describes the first stage, where the current heat demand is represented on the left, and the heat potentials produced with different technologies are represented in the stacked column diagram on the right. By comparing the two graphs, the main outcome is that the total available current heat potential, calculated as 31.3 PJ, in case that solar collectors produce an average heat amount of 3PJ since 6 PJ is considered as the maximum (see sub-section 5.1.2), overcomes the current heat demand of 25 PJ, giving the opportunity of utilising multiple renewable energy technologies for covering the need for heating.

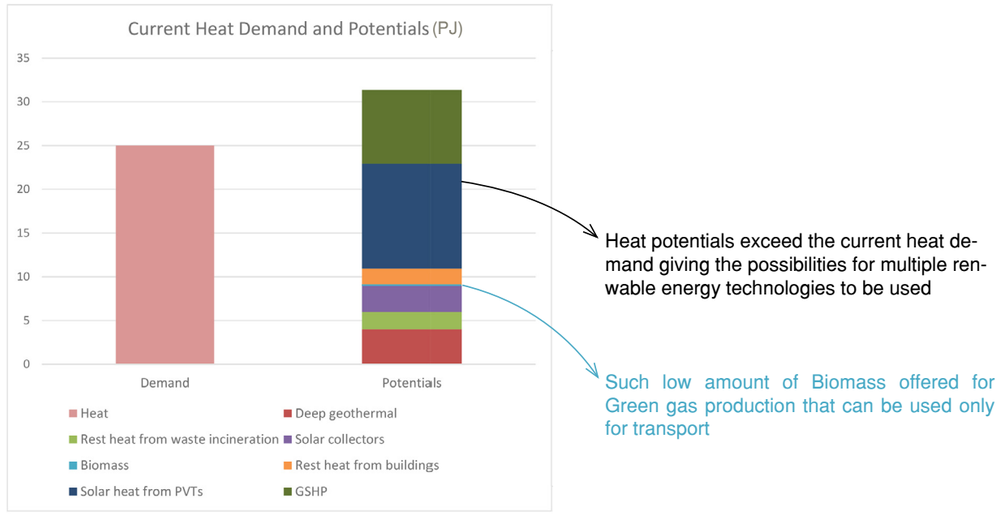


Fig. 45: Comparison of the current heat demand and the current renewable energy potentials

Next graph shows a scenario, formulated for fulfilling the remaining heat demand for space heating and DHW in 2050. The heat systems chosen for covering the demand are separated in two categories. The first concerns LT heat, which includes ATES and GSHP systems, and the second HT heat including the heat from waste incineration and from deep geothermal.

fering 4PJ, are added to feed the DHN and cover a part of the future demand with HT heat. However, the quantity used from each technology cannot be known accurately, fact that makes the assumption of using 4 PJ from the available amount of 7 PJ to cover the demand look safe. Regarding the amount of LT heat, there are enormous heat potentials for meeting the remaining needs efficiently. Still, the

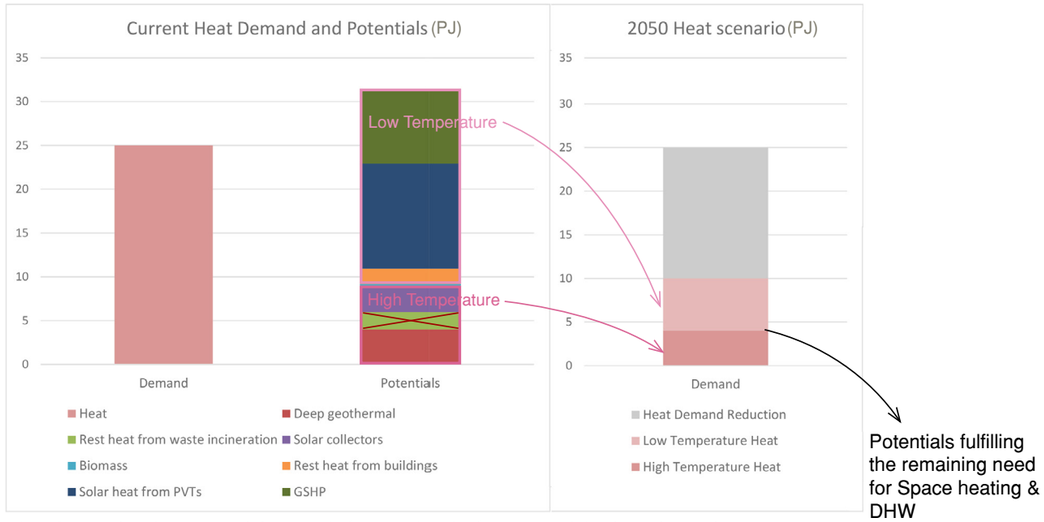


Fig. 46: LT and HT heat potentials scenario for covering the future remaining heat demand

At this stage of the scenario, the LT and HT sources are sorted to fill the remaining heat demand in 2050, justifying the decision of 60% reduction. LT heat, seems to be pretty high reaching the value of 31.3 PJ, which is about 3.5 times higher than HT heat of 9 PJ. For defining the 2050 HT heat potential, it is assumed first that not enough domestic waste will be available for waste incineration, taking into account the ambition of recycling becoming a daily process for all citizens. That means that the heat from solar collectors with average potential of 3 PJ, and from deep geothermal systems of-

LT technologies used in the future cannot be predicted, concluding that 6 PJ is a reasonable amount for covering the heat demand. Consequently, a percentage of 60% reduction of the heat demand of the whole housing building stock in Amsterdam seems like an approachable target showing the minimum reduction that should be achieved.

Determining the amount of the LT heat potential was certainly needed for calculating the electricity demand for the heat pumps that operate with the LT systems. The average COP of the heat pumps is

considered as 3 (feedback from domain expert), resulting in electricity demand of 2 PJ. The potential sources for electricity production in 2050 (recall chapter 5.1.2) show that the electricity demand of heat pumps can be certainly filled by renewable sources, as the total electricity potential is 7 PJ.

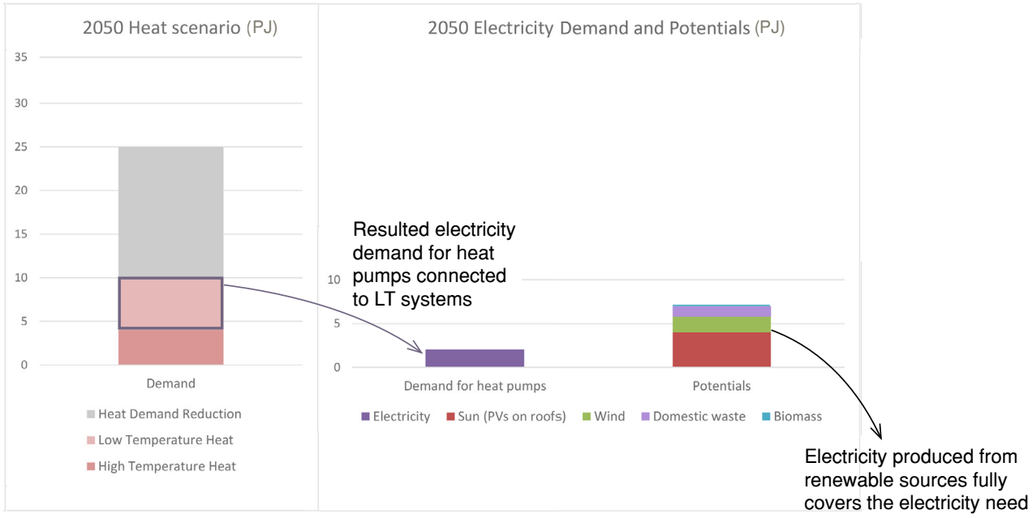


Fig. 47: Comparison of the future electricity demand for heat pumps with the electricity potentials from renewable sources

A main conclusion of this scenario is that the city's heat demand of 10 PJ in 2050, from which 4 PJ are covered by HT heat potentials and the rest 6 PJ by LT. In addition, the future heat demand and the electricity need for operating the installed heat pumps can be fully covered by renewable sources. The resulted electricity demand for heat pumps connected to LT heat systems is covered as well by renewable energy potentials. However, the specific project does not occupy with the electricity demand for housing appliances that cannot be covered by renewable sources as it reaches the value of 16.5 PJ (sub-section 5.1.1).

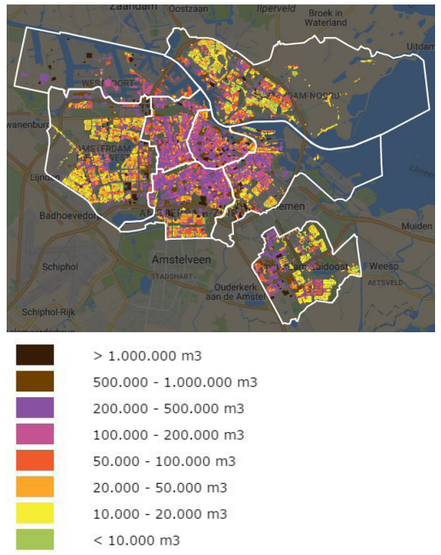


Fig. 48: Map of gas demand (source: http://maps.amsterdam.nl/)

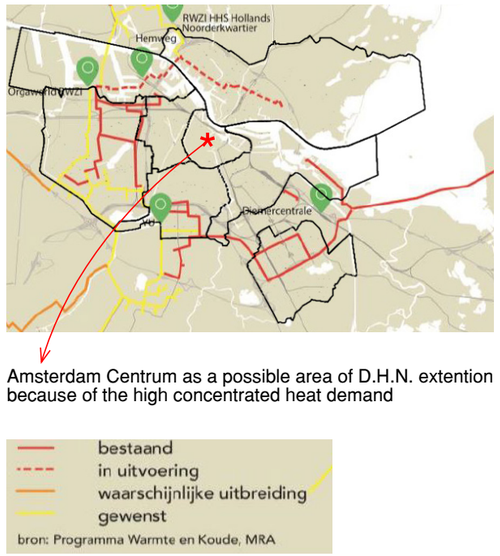


Fig. 49: Regional warmtenet 2015-2040 (source: Gemeente Amsterdam, 2016)

5.3.2 Main heat systems ratio in each district

The exploitation of the developed scenario to divide the main heat systems ratio in each district certainly contributes at the allocation of the systems in terms of percentages, so that the 6PJ of LT heat and the 4PJ of HT heat are divided in the different districts of the city in a critical and logical way. This goal is proceeded by looking at the gas consumption map, that indicates which districts have higher heat demands than others (e.g. the center seems to have the highest demand), and then at the DHN map of future extensions, to conclude how much HT heat is provided in each district. Also, for this project an assumption was that the DHN is going to be extended also in the centre of the city, beside the Noord district, since there is high heat density concentrated in that area. Thus, HT heat will be provided to all districts through the local DHN.

Proposing that the DHN passes through all districts without exception, an estimation for the percentage of HT heat systems and LT heat systems is made for each district separately. This estimation is based on how much area the DHN seems to cover, and by adding the HT amounts provided to all districts, they should result 4 PJ and all LT heat potentials should result 6PJ to fulfill the demand of 10 PJ in 2050. This data is listed in the following table which is used to create a map where the results are visualised. The difficulty at this point is that the results cannot be fully accurate, guiding to solutions of percentages representing the general categories of HT, depending on how much area the DHN covers, and LT heat systems for the rest of the area inside each district.

Amsterdam district	Heat demand 2050	H.T. or L.T. Heat Systems	Percentage	Heat Potential
Centrum	1.5	High Temperature	50%	0.7
		Low Temperature	50%	0.7
Oost	1.2	High Temperature	20%	0.2
		Low Temperature	80%	1.0
Zuid	1.5	High Temperature	50%	0.7
		Low Temperature	50%	0.7
West	1.5	High Temperature	20%	0.3
		Low Temperature	80%	1.2
Nieuw-West	1.2	High Temperature	50%	0.6
		Low Temperature	50%	0.6
Westpoort	0.7	High Temperature	30%	0.2
		Low Temperature	70%	0.5
Noord	1.2	High Temperature	50%	0.6
		Low Temperature	50%	0.6
Zuidoost	1.2	High Temperature	45%	0.5
		Low Temperature	55%	0.7
	Total heat demand 2050			Total H.T. Heat potential
	10.0			4.0
				Total L.T. Heat potential
				6.0

Table 7: Heat distribution per district in 2050

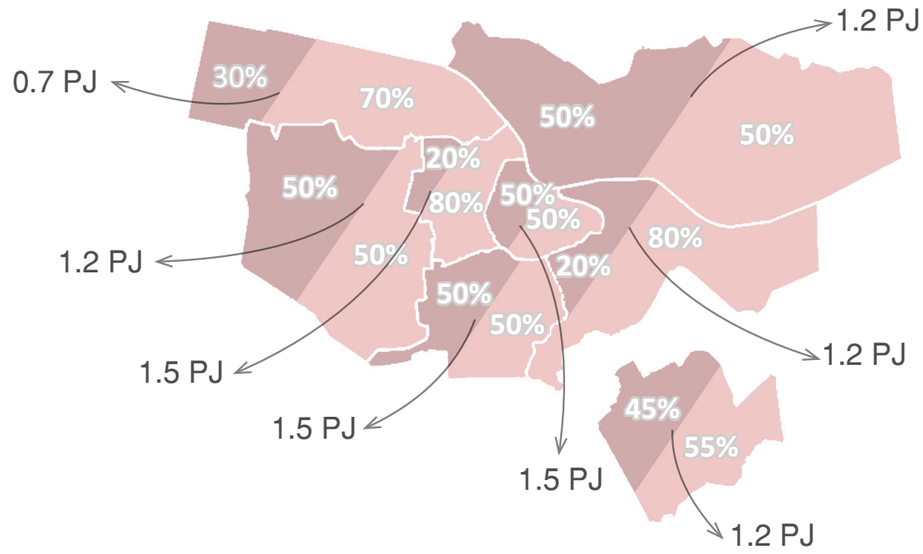


Fig. 50: LT and HT energy systems ratio covering the future heat demand

5.3.3 Classify energy systems

Returning to the context analysis of Amsterdam city to take a look back at the existing proposals for specific alternative energy systems and their future application scenarios help in setting several basic energy systems for retrofit interventions, formulating more unified solutions (sub-section 3.1.1). The suggested basic systems include the use of green gas, the connection of more building blocks to the DHN, the use of heat and cold storage (ATES system), and the transition of existing dwellings to All-electric. By knowing the energy potentials from renewable sources that correspond to each system, the most suitable systems can be classified.

Even though, the use of green gas might result a possible energy system, it is excluded because of the small amount of available biomass, leading to the solutions of Small-scale heat network connected to ATES system, of the transition of dwelling to All-electric or NOM when possible, all of them providing LT heat, and to the use of DHN, providing HT heat (figure 51). The map of the main energy systems ratio, shows percentages of areas where the systems are mixed, under the mentioned general categories of LT and HT heat systems.

This classification of the energy systems is useful, in order to make the transition of proposing systems for city scale to proposing systems on neighbourhood scale easier, since the existing energy systems vary.

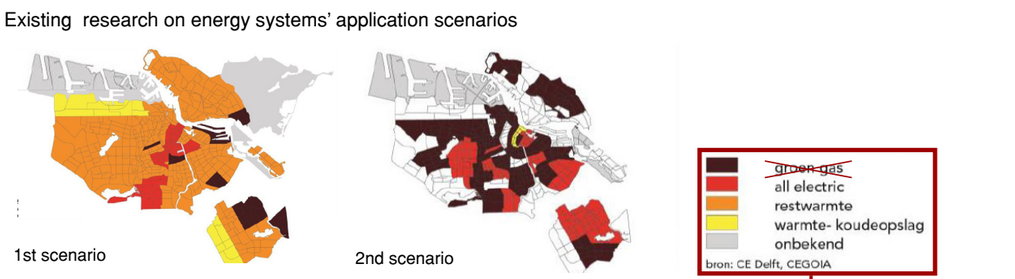


Fig. 51: Existing scenarios of on-site energy systems applications (source: Gemeente Amsterdam, 2016)

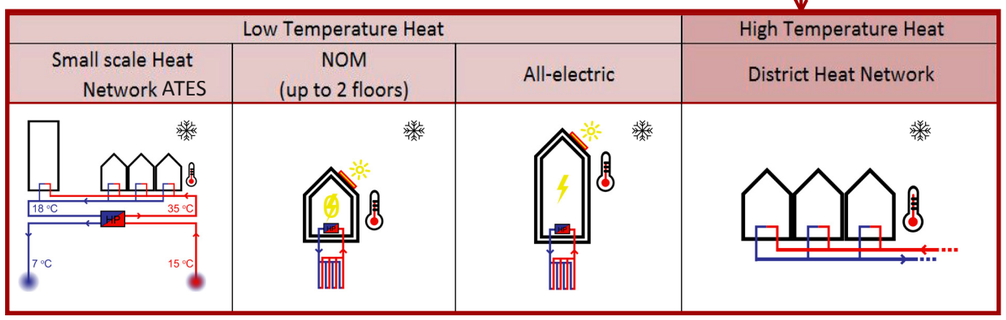


Fig. 52: Classified energy systems

06

APPLICATION OF METHODOLOGY STEPS ON NEIGHBOURHOODS OF AMSTERDAM NIEUW WEST

In this chapter, the process of applying the developed energy urban planning methodology steps, refers to the neighbourhoods of Amsterdam Nieuw West district, for proposing solutions regarding smaller clusters of dwelling with similar construction and ownership characteristics.

6.1 MAP THE PRESENT

The procedure of mapping the present conditions of selected neighbourhoods inside Amsterdam Nieuw West is already conducted during the context analysis. Thus, in the following sub-sections, the useful information regarding the current energy demands and potentials of the area, for selecting suitable measures for these neighbourhoods is extracted.

6.1.1 Intervention site inside Amsterdam Nieuw West

For mapping the present of neighbourhoods in Amsterdam Nieuw West district, the first step is to determine a smaller number of neighbourhoods for retrofit interventions, because of the limited time for this project. This decision led to the selection of the Slotermeer-Zuidwest and Slotermeer-Noordoost neighbourhood combinations (recall sub-section 3.2.1).

6.1.2 Buildings description & energy demands

During data extraction process regarding the dwelling inside the intervention site, data about the typology and the energy consumption per building block is collected, that are crucial variables for the selection of suitable energy systems for each neighbourhood. This process contributed firstly in creating a map with the different typologies, that can be used later with the maps of housing corporations property, revealed from literature review as shown below (figures 54, 55), for formulating clusters of buildings with the same construction properties and ownership status afterwards

The current heat demand of each dwelling is calculated as 90% of the gas demand (figure 56), assuming that gas boilers of 90% average efficiency are used, (recall sub-section 3.2.2), which is essential for the application of the roadmap aiming at the optimisation of the energy use for heating space and for DHW. The existing pathways of the local DHN are also important to be known (figure 57), since this heat system results a great possibility for heating the nearby building blocks.

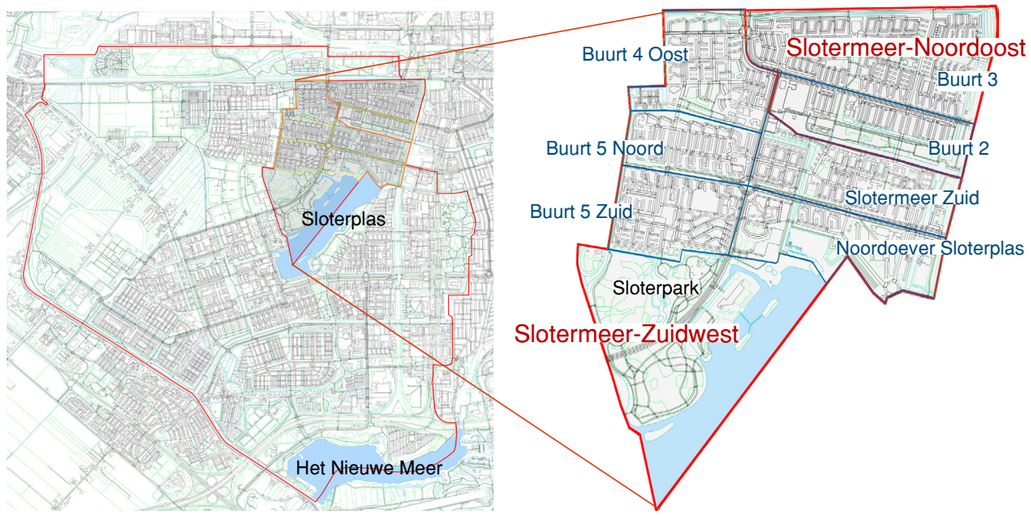


Fig. 53: Selected neighbourhoods inside Amsterdam Nieuw West district

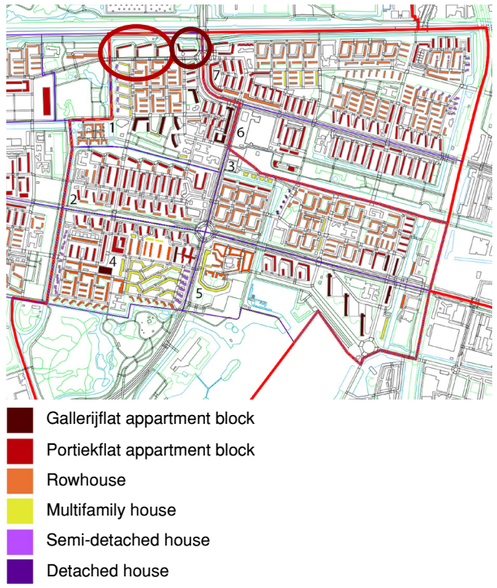


Fig. 54: Map of typologies

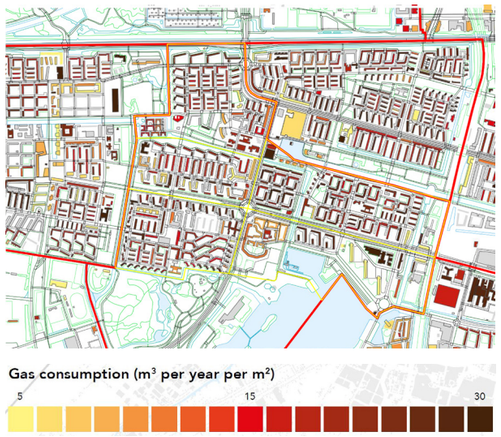


Fig. 56: Map of average gas consumption (source: Geert den Boogert et al., 2014)

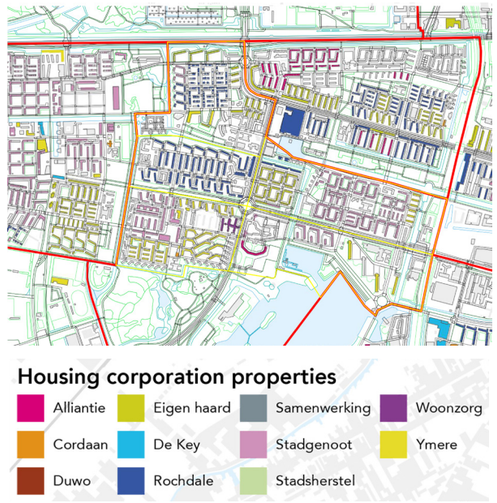


Fig. 55: Map of housing corporation properties (source: Geert den Boogert et al., 2014)

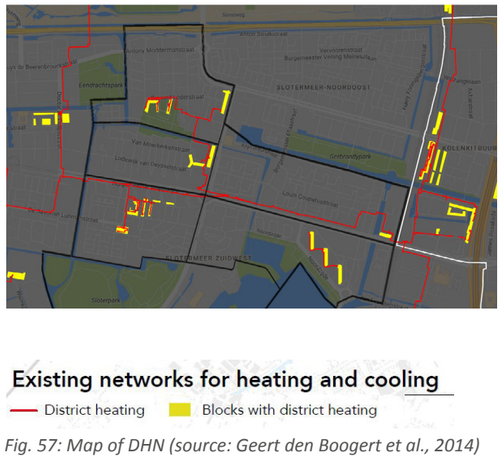


Fig. 57: Map of DHN (source: Geert den Boogert et al., 2014)

Finally, the information of typologies levels number, of the ownership status, of the existing DHN pathways and of the average heat demand per m2 are implemented on a three-dimensional heat map, to construct an idea of the levels of heat consumption for each housing block. This heat map will be used in the roadmap stage to show the changes in heat consumption during time, by applying the suitable energy systems and retrofit measures (figure 58).

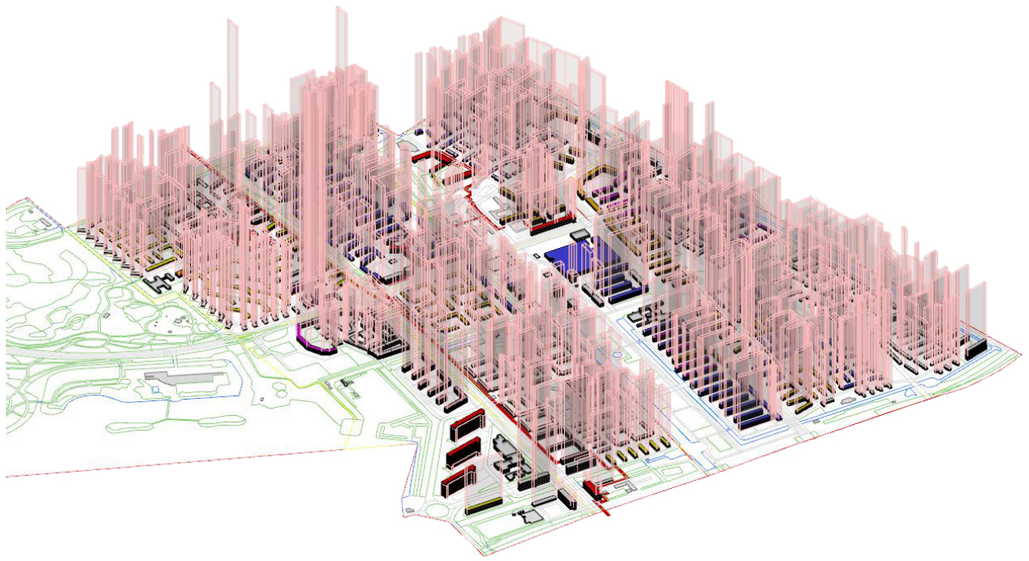


Fig. 58: 3-dimensional heat map for concentrated data visualisation

6.1.3 Energy potentials

An indispensable factor contributing at the selection of the suitable local heat systems, is the collection of the energy potentials (recall sub-section 3.2.3), that can be utilised on neighbourhoods for collective solutions, and on buildings for individual applications. After the process of classifying the energy systems, the important energy potentials seem to include the open loop thermal energy storage (ATES) and the potential of residual heat from non-residential buildings for using LT small scale heat network in a neighbourhood when possible, the closed loop thermal energy storage (GSHP) for individual applications, and the deep geothermal offering heat to the DHN, and thus to the buildings connected to it in the future.

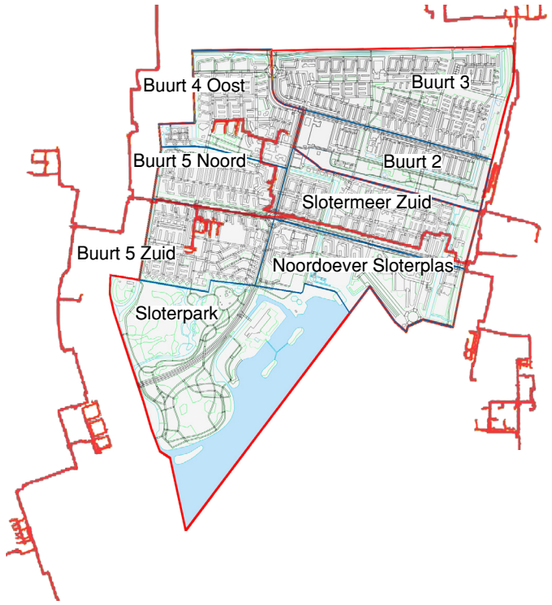
6.2 DEFINE FUTURE ENERGY TARGETS

In this section, the definition of the energy targets of 2050 for the selected neighbourhoods in Amsterdam Nieuw West is required. The energy reduction goal regarding the heating demand of these neighbourhoods does not have to follow the same goal as for the whole city. As already explained in sub-section 5.2.2, the average energy reduction for heating purposes of all districts is set as 60%. However, in some areas the percentage achieved can be less, like in the centre, due to the intervention restrictions for protecting the historical buildings. This is why in more recently built areas, like in the case of Amsterdam Nieuw West district which mainly started being built in 1946, a higher reduction percentage can be achieved.

The logic for setting an energy target for the selected neighbouroods is also based on the project of Europe's buildings under the microscope, which supports that the most economical energy transition pathway is achieved by retrofit in stages, the minor, moderate, deep and nZEB retrofit (recall sub-section 2.6). Minor retrofit aims at 30% energy reduction, moderate at 30%-60% reduction, deep retrofit represents a reduction of 60%-90% energy reduction, and nZEB is the stage where renewable energy technologies are used to cover as much as possible the remaining demand.

6.2.1 Desired future heat demand

By following the target of deep retrofit, the percentage of heat demand reduction considered to be achieved is the average of 60%-90% energy reduction, leading to the goal of 75% heat demand reduction. Since the heat demand of each housing block is figured out through context analysis, a total for each neighbourhood is calculated (table 8). Thus, the total heat demand of all neighbourhoods is 0.41 PJ, and the remaining heat demand should reach the value of 0.10 PJ.



Nieuw-West_Sloteermer neighb.	Heat demand kWh 2017
Buurt 4 Oost	5504688
Buurt 5 Noord	15962339
Slotermeer Zuid	15962339
Buurt 5 Zuid	24676013
Noordoever Sloterplas	10734521
Buurt 3	29793499
Buurt 2	12289597
	114922996
	Heat demand PJ 2017
	0.41
	Heat demand PJ 2050
	0.10

Table 8: Current and desired 2050 demand heat demand

6.2.2 Low and HT heat potentials & technologies for each system

The percentage of DHN heat provided to cover the demand is assumed to be bigger than LT heat as the existing DHN, as a HT heat system, passes through 4 out of 7 neighbourhoods, indicating that it is the most suitable solution for these 4 neighbourhoods. LT heat can cover the rest with the use of the corresponding LT heat systems.

In the following table, the heat and electricity production systems are categorized under the respective basic energy system. The placement of the certain renewable energy technologies under each specific system is based on literature review (recall section 2.4).

Low Temperature Heat			High Temperature Heat
Small scale Heat Network	NOM (up to 2 floors)	All-electric	District Heat Network
ATES	GSHP	GSHP	Deep Geothermal
Rest heat from buildings	PVT	PVT	Rest heat from waste incineration
PVT	PVs	PVs	Solar Collectors are possible

Table 9: Corresponding technologies to the classified basic energy systems

6.3 STRATEGY FOR SELECTING ENERGY SYSTEMS

For comprising a wholistic strategy for the selection of suitable energy systems for the clusters inside each neighbourhood, several variables for designating suitable energy systems for each case should be set and priority criteria for on-site interventions as well, in order to develope a decision-making diagram including all variables indicating suitable retrofit interventions on the appropriate time.

6.3.1 Set variables for selecting the suitable energy systems

As already mentioned, green gas is excluded from the basic energy systems, since biomass, the raw material for green gas production, is available in such a low amount that is assumed to be used in transport rather than for producing green gas for heating dwellings in several areas (recall sub-section 5.3.3). Consequently, this research will give solutions by using four energy systems, referring to the use of the existing DHN (HT), the creation of small-scale (LT) heat network connected to ATES, the transformation of existing dwellings in several areas to all-electric and the transition to NOM of others. What is missing before making a proposal for their on-site implementation in each neighbourhood of the intervention area, is the application requirements of each system. In the following paragraphs, the application requirements are identified and presented:

Small-scale heat network with ATES implementation requirements

For using this energy system, there must be buildings with excess heat and cold potential in the neighbourhood, like offices, supermarkets, hospitals and datacentres. Heating and cooling demands must be in equilibrium otherwise ATES system will become imbalanced and no longer function. Well-insulated dwellings with integrated floor and/or wall heating to make it possible to heat the building with LT heating. Also, this system is possible in case of big housing buildings with one owner of a big corporation (Gemeente Amsterdam, 2016).

NOM

It is a suitable retrofit solution for low-rise dwellings, because of the appropriate size of roof area offered for PVs and solar panels, comparing to the energy demand needed to be covered. Project of rowhouses of 60's and 70's, already finished show positive results for the approach. It is possible for individual home owners to be convinced, as well as in the case of a partnership with big corporations (Gemeente Amsterdam, 2016).

All-electric

The transition to all-electric is preferable for dwellings of more than 2 levels high, since low rise are possible for NOM, and results a possible solution for individual home owners & for big corporations (Gemeente Amsterdam, 2016).

DHN implementation requirements

Defining favourable locations to expand existing DHNs to, can be done by putting maps of the existing networks, to identify the areas with high the heat demand. In case that DHN already passes through a neighbourhood, connecting the existing dwellings seems to be the preferable solution. Also, a crucial question is whether there is one heating system and one administrator for a building block, since it seems easier to convince or motivate. If this is not the case, custom solutions could be discussed (Gemeente Amsterdam, 2016).

Variables for strategy configuration

Out of the process of identifying the application requirements of each basic energy system, several variables came out, that contribute at the configuration of a strategy that will determine the suitable systems for each neighbourhood of retrofit. In the diagram below, you can see the different variables. This strategy is going to take the form of a decision-making diagram, where these variables are organised, leading to solutions of suitable systems and retrofit stages when several variables are met.

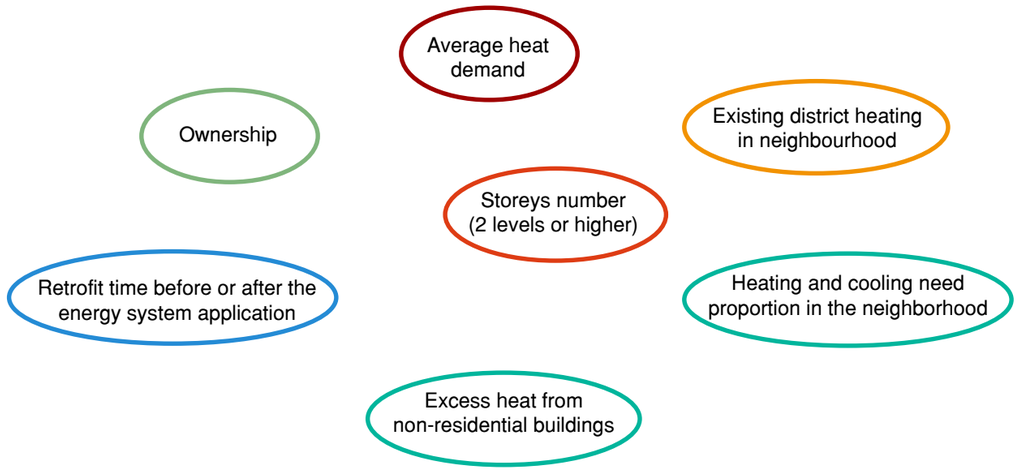


Fig. 59: Important variables decision-making approach configuration

6.3.2 Set priority criteria for on-site interventions

As an addition to the strategy of determining the suitable energy systems for each neighbourhood, some requirements should be indicated for prioritising the time of retrofit interventions for each dwelling. The idea is that every 5 years, all dwellings of all neighbourhoods will be evaluated based on the whole diagram, so that the retrofit interventions will be in stages, because the cost of applying all measures at once is too high.

The main variable to examine, is whether the average heat demand per m2 is high. The threshold of "high" heat demand is determined every time the buildings are inspected through this diagram. For example, at the initial check in 2017, the buildings that have heat demand higher than 300 kWh/m2, are chosen to be retrofitted first. This process is repeated at 2020 with buildings with heat demand higher than 250 kWh/m2, at 2025 higher than 200 kWh/m2, at 2030 higher than 150 kWh/m2, at 2035 higher than 100 kWh/m2 and at 2040 higher than 50 kWh/m2. Thus, all buildings until 2050 should reach the demand reduction goal of 75%.

Therefore, the first thing to check is if the heat demand of the building blocks in the neighbourhood exceed the determined threshold. In this case then the process goes on for the question if there is one owner for the building until the suitable energy system is selected. If the demand does not exceed the limit, the next thing to check is whether there are other dwellings of the same typology in the neighbourhood and if their demand in total is higher. If there are no other buildings that are the same they are low in priority and for a custom retrofit approach (figure 60).

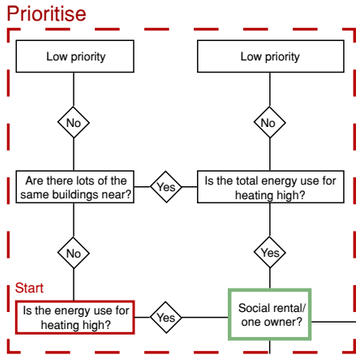


Fig. 60: Prioritising part of decision-making diagram

6.3.3 Develop decision-making diagram for on-site interventions on appropriate time

For the selection of the appropriate energy systems for the clusters inside each neighbourhood, a decision-making diagram is developed. This strategy includes organising the variables, that came out of the application requirements of each basic energy system as mentioned, on a decision-making diagram, to follow a straight process and give alternatives in case the answer to them is yes or no. This diagram leads on choosing the suitable energy systems combined with the retrofit steps, depending on the different energy and context characteristics of the existing building blocks in each neighbourhood (figure 61).

In this diagram, the first variable is about whether the building blocks in a neighbourhood are provided for social rental, since the owners agreement is necessary for applying the different proposed solutions. For this project, it is considered that when there is only one owner or administrator in a building instead of multiple it is easier to convince for a collective solution, like the dwellings' connection to the DHN or to a small-scale heat network. Also,

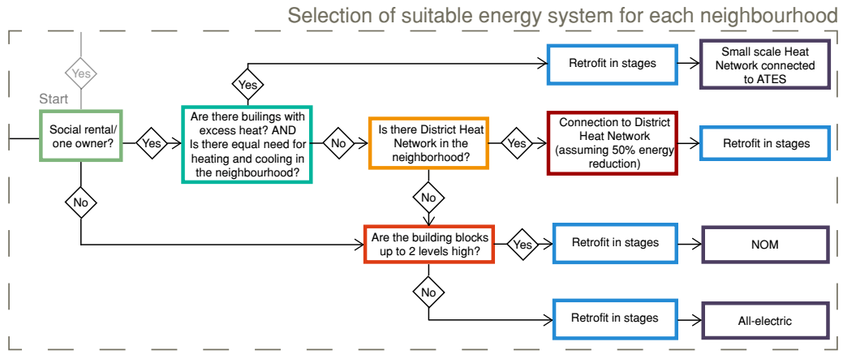


Fig. 61: Systems' selection part of decision-making diagram

in case of social rental, the owner is possibly a big corporation that owns other buildings in the neighbourhood, or in other neighbourhoods as well, and retrofit solutions can be proposed for multiple buildings at once.

In reality, when there are multiple owners, there are still the options for connection to DHN or to Small-scale heat network if all owners agree. However, the human factor of the owners' decisions cannot be examined through this decision-making diagram. Therefore, for simplifying the process, in case that the answer is yes to one owner, the proposed solutions are DHN or Small-scale heat network, and if the answer is no, meaning private ownership or multiple owners, it is considered as going directly for the solutions of transition to NOM or All-electric.

Furthermore, for the building blocks of social rental, the next step is to check if the requirements of excess heat from non-residential buildings, and of equal need for heating and cooling are met, to go for retrofit in stages, and then to use of Small-scale DHN connected to an ATES. If the answers each of these requirements is no, the next thing to check is if there is DHN in the neighbourhood. If DHN passes through the neighbourhood, the buildings can just be connected to it, and apply later retrofit measures in stages to reduce the heat demand even more. In these cases, the heat demand should not be reduced to almost zero because this case is not for the best interest of the heat providing company. Moving on to the case that there is no DHN near, the next variable to examine is if the building blocks are up to 2 levels high. If the answer is yes, the transition to NOM is an achievable goal, otherwise the buildings can be transformed to All-electric.

When Small-scale heat network with ATES, NOM, or All-electric are implemented, the retrofit should be done first for lowering the demand as much as possible, as both systems use LT heat. The retrofit process is suggested to be in stages, to make the intervention more economical than applying all retrofit measures at the same time (Economidou, M. et al., 2011).

For the completion of the decision-making diagram of selecting the suitable energy systems combined with the retrofit steps for the clusters inside each neighbourhood, the part of prioritising the dwellings for intervention is added before the selection part of the diagram as it always comes first.

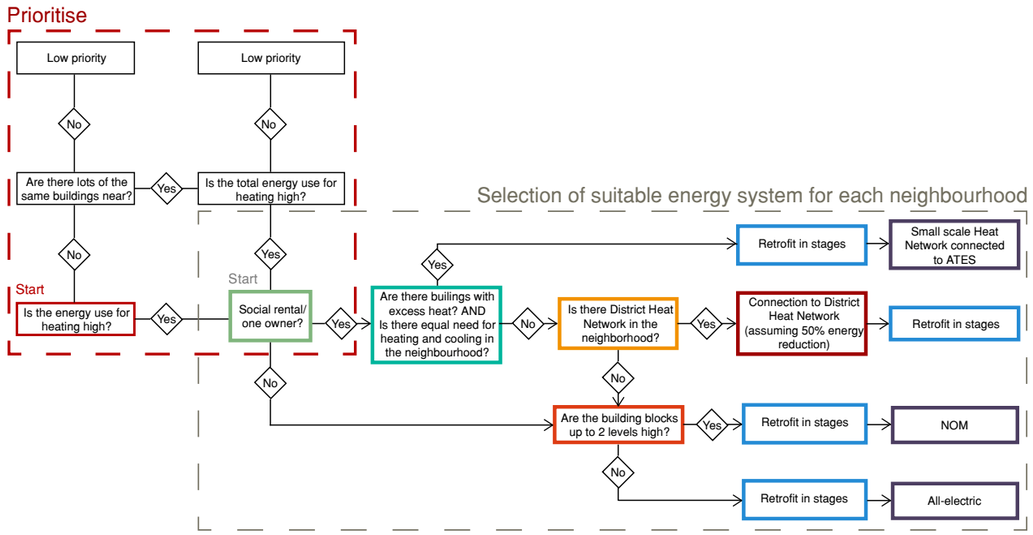


Fig. 61: Decision-making diagram for on-site interventions on appropriate time

07

ROADMAP DESIGN

The final outcome of the roadmap, as the last step of the 4-step energy urban planning methodology, consists of 3 sub-steps which are 1) the selection of suitable energy systems for 2050 for each one of the selected neighbourhoods, 2) the description of the energy system and retrofit measures, and the corresponding changes in heat demand and CO2 emissions are listed in templates, and 3) the definition of the interventions determined by the 2 previous sub-steps on timeline, starting from today and ending in 2050.

7.1 DEFINE SUITABLE ENERGY SYSTEMS IN 2050 FOR EACH NEIGHBOURHOOD

The implementation of the decision-making diagram (sub-section 6.3.3) intends to formulate the vision for the area in 2050, represented on a map of the area, that also shows with different colours the buildings that belong to different housing corporations and the existing DHN. While following the diagram to propose solutions on neighbourhood scale, it was realised that different systems can be combined inside each neighbourhood leading to solutions for smaller clusters of dwellings. This happens because of the different energy and construction characteristics of each building, and also because of all the stakeholders that should collaborate, that play a prominent role to the transition to gas-free dwellings and neighbourhoods. The term stakeholders include the energy suppliers, and the housing associations and property owners, that should be convinced that the proposed solution is the most suitable for their property.

Several examples for each neighbourhood follow below, to show how the decision-making diagram helps in organising the dwellings with same ownership status and typology characteristics in clusters for proposing unified collective (DHN or small-scale heat network with ATES) or individual solutions (transition to NOM or All-electric) for the energy systems' applications.

Buurt 4 Oost

Regarding Buurt 4 Oost, the neighbourhood is separated in 3 clusters, mainly based on the ownership status. The first cluster is consisted of multistory dwellings of social rental. In cluster 2, there are 2-story rowhouses of mixed ownership, i.e. some apartments offered for social rental and some for private ownership in the same building block, and in cluster 3 there are rowhouses of private ownership. Since there is such a small amount of excess heat from offices and the existing DHN passes through this neighbourhood, the decision taken for the 1st cluster is to fulfill the heat demand by the DHN. Regarding the second cluster, since there are several owners and the dwellings are two levels high, the retrofit in stages and transition of these dwellings to NOM seems to be a suitable solution. The same flow is followed in the diagram for the 3rd cluster of newer rowhouses of private ownership, leading to the solution NOM as well. The different ways that the decision-making diagram is applied, based on the specific variables met for each cluster guiding to the suitable retrofit solution are shown below.

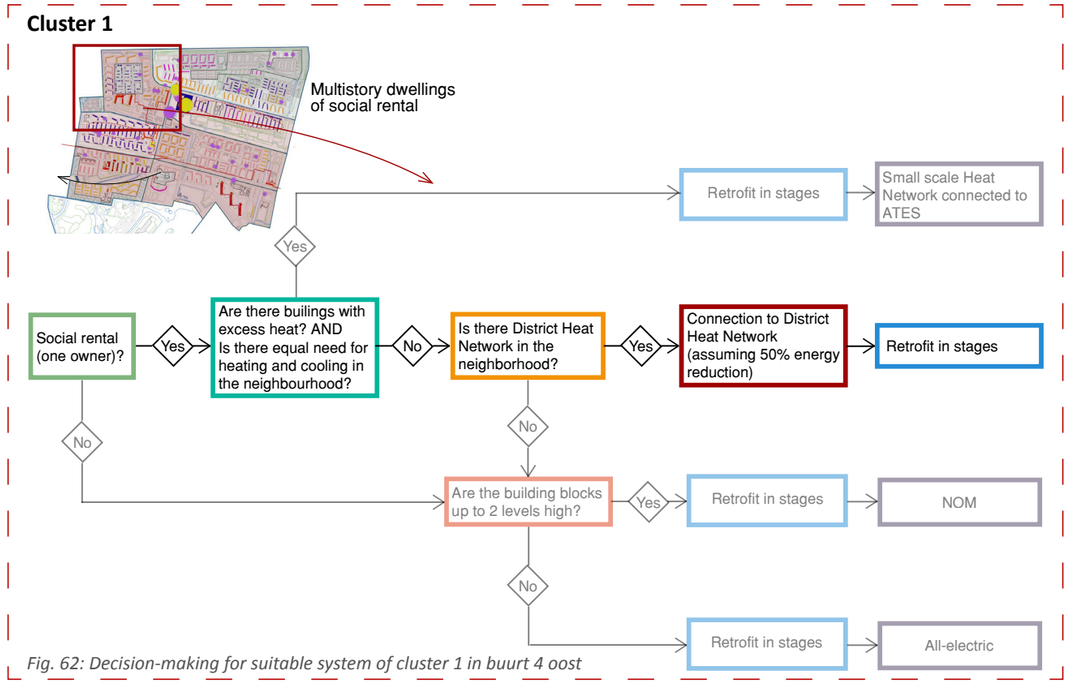


Fig. 62: Decision-making for suitable system of cluster 1 in buurt 4 oost

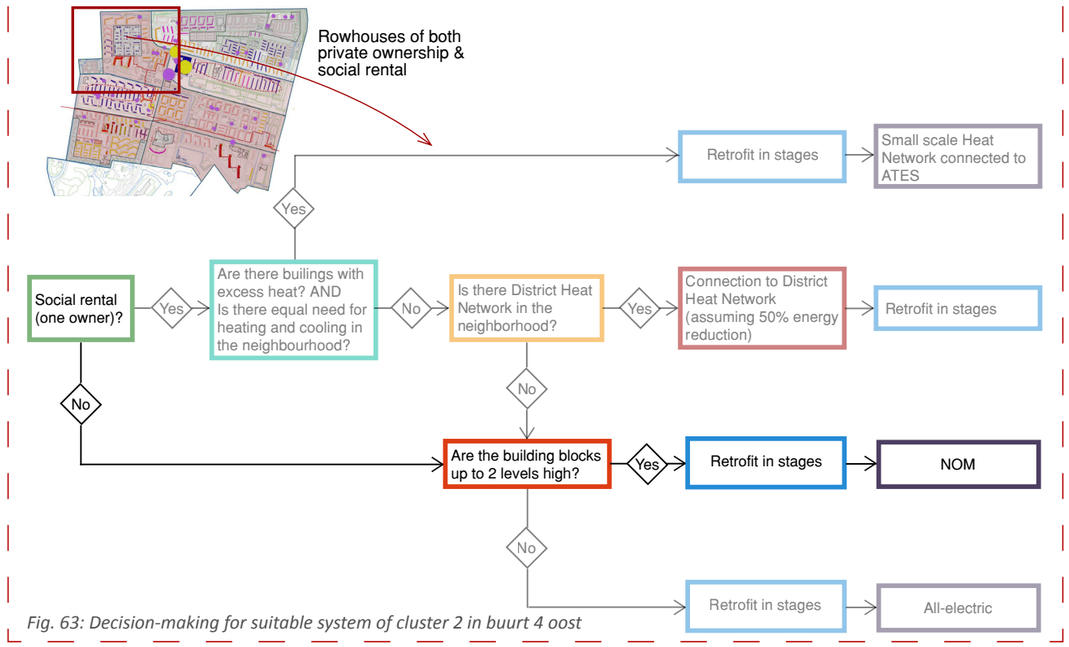


Fig. 63: Decision-making for suitable system of cluster 2 in buurt 4 oost

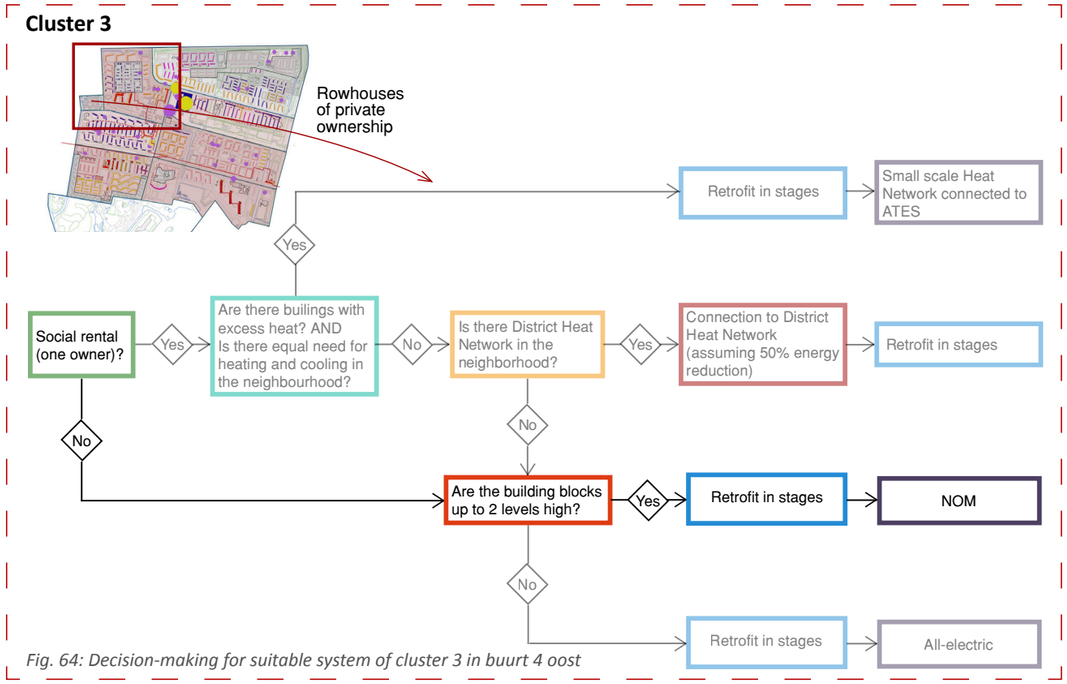


Fig. 64: Decision-making for suitable system of cluster 3 in buurt 4 oost

Buurt 3

In the case of Buurt 3, three different cases are faced again. As noticed first, in the neighbourhood there are no buildings with excess heat and no DHN. Thus, the main differences of the dwellings' characteristics depend on the ownership status and on the number of levels. Cluster 1 includes a number of rowhouses of private ownership which are two levels high. Cluster 2 includes rowhouses of social rental with two floors. Both cases meet the variables that lead to the solution of the dwellings' transition to NOM. In cluster 3, there are multi-story dwelling that belong to big housing corporations leading to the proposal of their transition to all-electric.

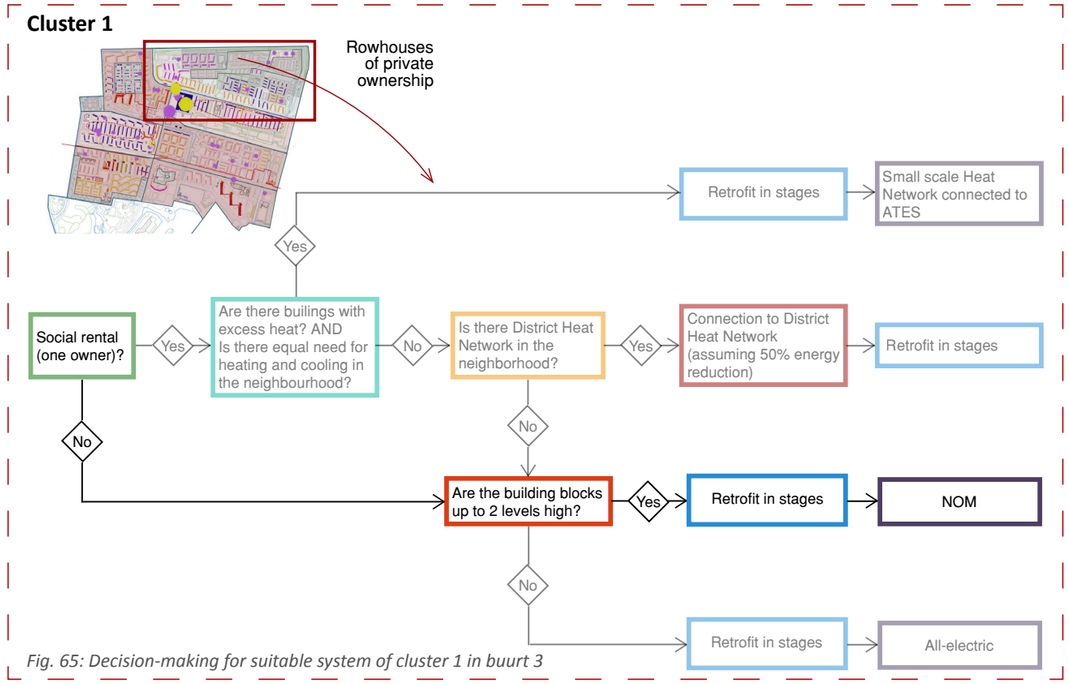


Fig. 65: Decision-making for suitable system of cluster 1 in buurt 3

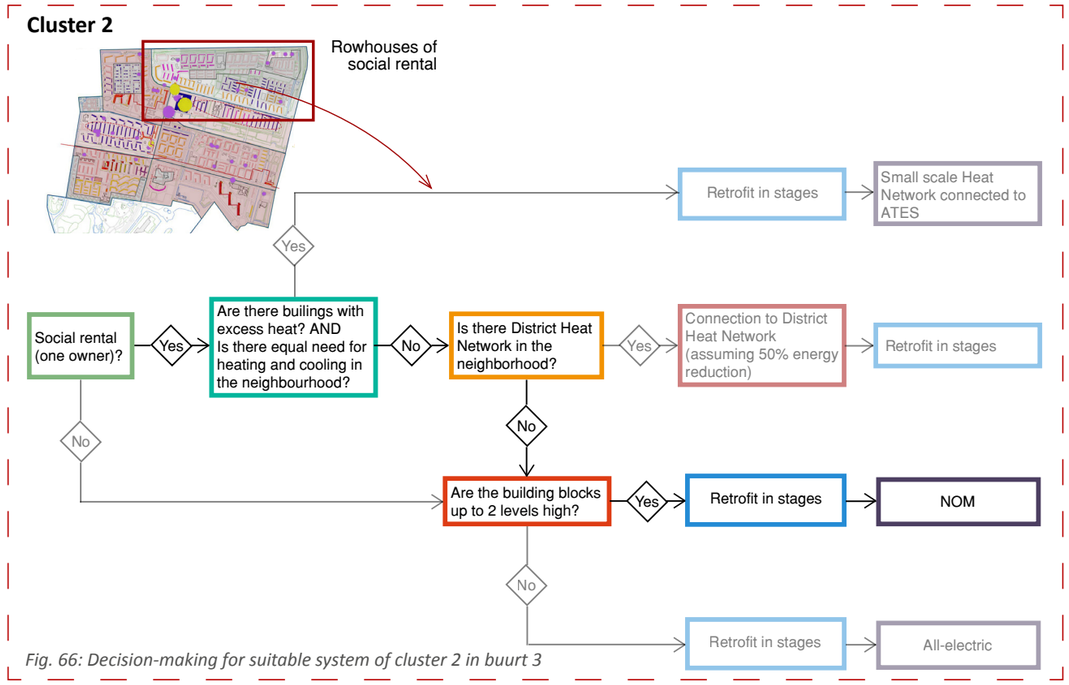


Fig. 66: Decision-making for suitable system of cluster 2 in buurt 3

Cluster 3

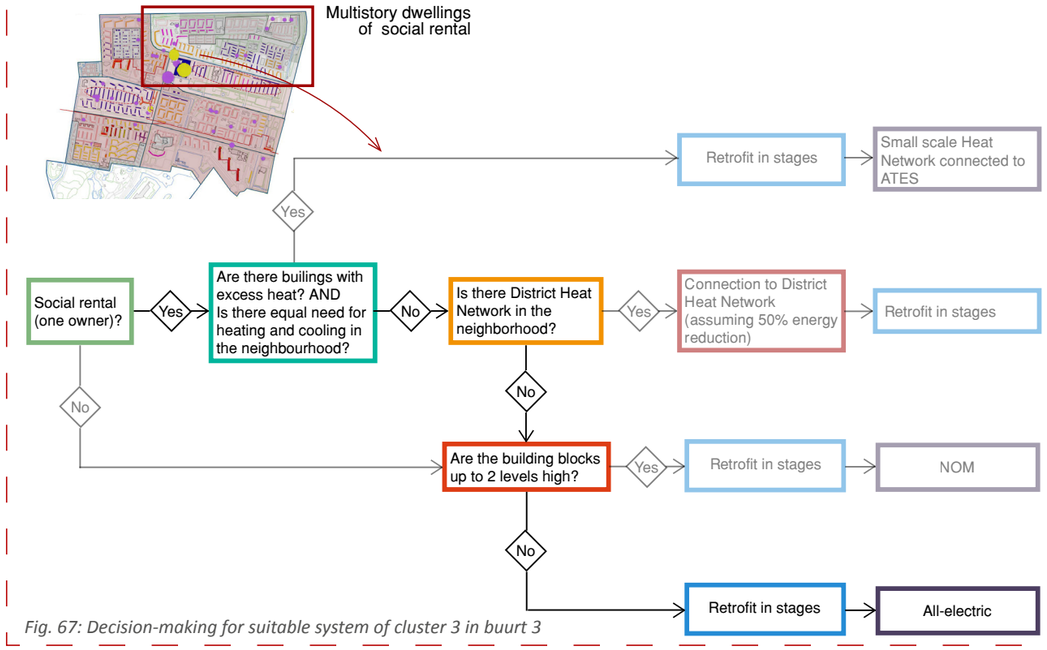


Fig. 67: Decision-making for suitable system of cluster 3 in buurt 3

Buurt 5 Noord

In Buurt 5 Noord, all dwellings in the neighbourhood have one owner which is a big housing corporation. Most of them are multistory dwellings of social rental. The high levels of heat demand (context analysis) in combination with the excess heat offered from non-residential buildings, indicate the creation of a LT small-scale heat network connected to an ATES system as the most suitable solution, applied after the deep retrofit of the dwellings. Although there are a few rowhouses it makes it much easier to go for one unified solution for the whole neighbourhood since only 1 owner needs to be convinced.

Cluster 1

Fig. 68: Decision-making for suitable system of cluster 1 in buurt 5 noord

Buurt 2

The case of Buurt 2 looks pretty much the same as the case of Buurt 5 Noort. This time, all dwellings in the neighbourhood belong to several big housing corporation. There are only multistory buildings of social rental with high heat demand, and a lot of excess heat offered from supermarkets and offices in the neighbourhood. The creation of a LT small-scale heat network connected to an ATES system, seem to be a suitable solution as well.

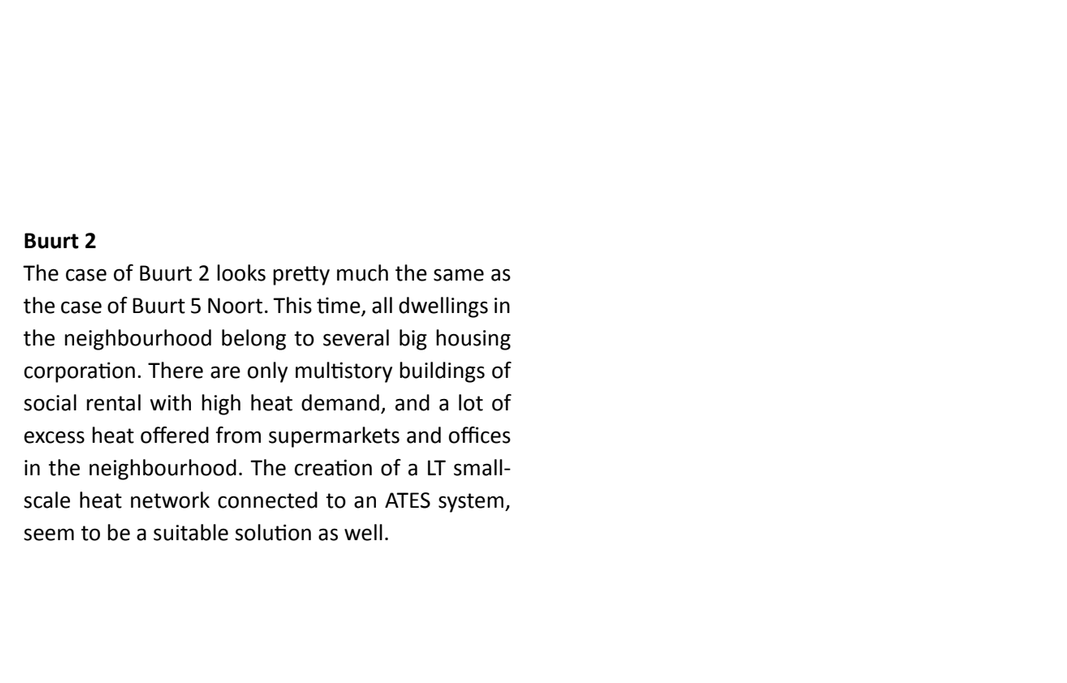


Fig. 69: Decision-making for suitable system of cluster 1 in buurt 2

Proposed solutions for Slotermeer neighbourhoods

It is noteworthy to mention that the results cannot be presented as absolute solutions. This is a fact since first of all, the stakeholders play a dominant role with their decisions. For example, a building of mixed ownership could go for a collective solution only if all owners agree. Since this is hard to be predicted, it is assumed that it is easier to just go for individual solutions. Secondly, this happens because of the fact that the technologies and the availability of renewable sources can alter through the period of 33 years until 2050. This result offers a possible methodology for decision-making, that could be followed by Amsterdam municipality that has an overview of the context and energy conditions, for achieving the energy transition of the specific part of Amsterdam Nieuw West with more unified solutions.

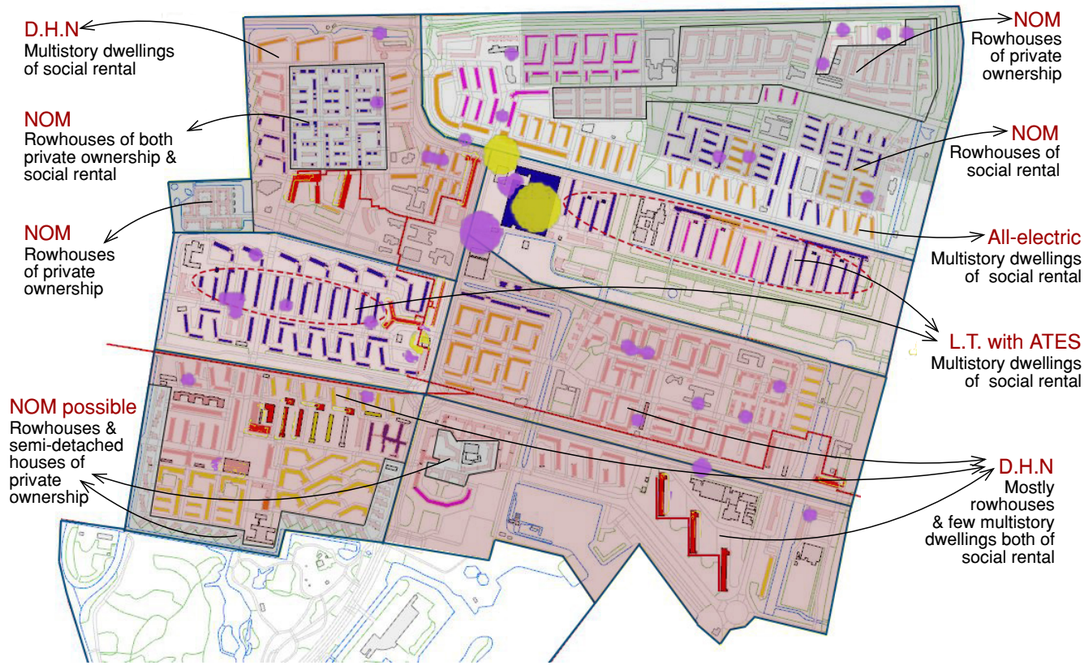


Fig. 70: 2050 vision of suitable energy systems of all neighbourhhods

7.2 DESCRIBE ENERGY SYSTEMS & RETROFIT MEASURES LEADING TO 2050 VISION

In this sub-section, description templates are filled out, to provide a complete image for the retrofit measures and energy systems used for retrofitting the different clusters of dwellings of similar energy and construction conditions in each neighbourhood. This description is conducted in the stages of current heat demand, heat demand reduction, heat production and electricity production. The changes in heat demand, as well as in CO2 emissions, are calculated in every stage until the demand is balanced. Electricity production is considered only for the balancing the electricity demand of heat pumps, that are used when LT heat systems are implemented.

These templates are inspired by City-Zen project's templates, and four templates will be provided, one for each energy basic system for the corresponding cluster of dwellings, as classified in sub-chapter 5.3.3. These systems represent the collective solutions of the connection to the DHN and of the Small-scale heat network connected to ATES, and for individual solutions of the transition of building to All-electric or NOM.

The current conditions are shown in step 0 starting with the total current heat demand and CO2 emissions. The retrofit measures are positioned in step 1 regarding the reduction of heat demand and CO2 emissions, which follows the goal of 75% reduction. Renewable energy systems are placed in steps 2 and 3 for heat and electricity production respectively, in order to cover the remaining demands, where CO2 emissions are eliminated except for the case of DHN that CO2 is emitted through the incineration process. The energy demand is expressed in MWh per year and the CO2 emissions in tCO-2eq per year, just like in the respective templates of City-Zen project.

One example for each heat system follows below:

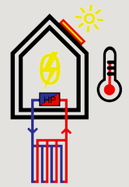
Buurt 3

Concerning Buurt 3, there are two proposed solutions for two different parts of the neighbourhood. The first template represents the solution of the energy transition of existing dwellings to NOM for cluster 1 and 2, and the second represents the solution of the transition to All-electric for cluster 3, mainly because of the different in the storeys numbers.

Fig. 71: Cluster 1& cluster 2 inside buurt 3

Transition to NOM for cluster 1 & cluster 2

In step 0, the current demand for heating is identified through the context analysis as 14363 MWh/year and the CO2 emissions as 2908 tCO2eq/year (reference), for 124 two-storey rowhouses and multifamily houses of social rental and private ownership with poor energy performance. In step 1 the heat demand is reduced to 3591 MWh/year and CO2 to 727 tCO2eq/year according to the goal of 75% energy reduction, after applying retrofit measures for improving the insulation of the houses and for improving the efficiency of the installations. The measures are described in more detail in the upcoming template. In step 2, a GSHP with ver-

PRINCIPLES	STEPS AND FEATURES	RESULTS
0. EXISTING SITUATION 	Features: • 124 multifamily and rowhouses, some for social rental and some of private ownership • poor energy performance	Heat demand H 14363 MWh/y CO2 2908 tCO2eq/y
1. DEMAND REDUCTION 	Insulation: • roof, walls, roofs • high performance windows Installation efficiency: • Smart appliances • change heating system • efficient mechinical ventilation with heat recovery • shower heat exchangers	Remaining heat demand H 3591 MWh/y CO2 727 tCO2eq/y
2. HEAT PRODUCTION 	• Transition to NOM energy system • Individual GSHP with horizontal heat exchanger • Heat pump is used with GSHP system_the electricity used is produced by renewable sources	Remaining heat demand & Electricity demand for heat pump with COP = 6 H 0 MWh/y CO2 0 tCO2eq/y E 599 MWh/y
3. ELECTRICITY PRODUCTION 	PV on roofs: • 9 m2 per roof	Remaining heat & Electricity demand H 0 MWh/y E -60 MWh/y

Template 1: Description of measure used in steps leading to 2050 vision for cluster 1 & cluster 2 in buurt 3

E=A*r*H*PR

Orientation		South	South-East	South-West
A (toral PV area m2)				1116
r (solar panel yield %)	0.8			
H (annual average irradiation m2 kWh/m2/year)		1180	820	820
PR (performance ratio 0.9-0.5)	0.9			
E (energy produced by the PV panel kWh)				658886

Table 10: Electricity production be PV panels on roofs

tical heat exchanger is selected to cover the need for heating, and CO2 emissions are eliminated as well. The heat pumps with COP of 6, installed in each house individually create in total the electricity demand of 599 MWh/year. In step 3, concerning the electricity production for fulfilling the mentioned demand, 9 m2 of PV panels are proposed to be installed in each roof, that produce in total 659 MWh/year to cover the need for the heat pumps of all houses, exceeding the demand by 60 MWh/y. The quantity that corresponds to each house can be used for user related purposes.

The electricity produced from PV panels is calculated through the formula of E=A*r*H*PR. In this equation E symbolizes the energy produced by PV panels in kWh, A is the total area of PV's in m2, r is the solar panel yield in %, H is the annual average irradiation for tilted panels in kWh/m2/year, and PR the performance ratio of the panels by considering all energy losses with a range between 0.9-0.5. The solar panel yield is taken into account as 0.8 and the performance ratio as 0.9 (feedback from expect), and the annual average irradiation for Amsterdam city is revealed from http://solarelectricityhandbook.com/solar-irradiance.DHNml for tilted panels.panels in kWh, A is the total area of PV's in m2, r is the solar panel yield in %, H is the annual average irradiation for tilted panels in kWh/m2/year, and PR the performance ratio of the panels by considering all energy losses with a range between 0.9-0.5. The solar panel yield is taken into account as 0.8 and the performance ratio as 0.9 (feedback from expect), and the annual average irradiation for Amsterdam city is retrieved from http://solarelectricityhandbook.com/solar-irradiance.DHNml for tilted panels.

Transition to all-electric for cluster 3

The rest of buurt 3 consists of 45 multi-story building blocks of social rental that need in total 15430 MWh/year and emit 3124 tCO2eq/year, as shown in step 0. In step 1, the same retrofit measures are applied as in the previous case, leading to 3858 MWh/year heat demand and to 781 tCO2eq/year. Going to step 2, GSHP systems are used again in individual applications, to cover the heating demand, creating the need for 643 MWh/year. This demand is covered in step 3 with the installation of 25m2 per roof that produce 664 MWh/year, 21 more than needed for heat pumps' operation.

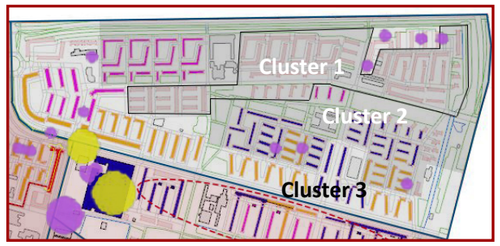
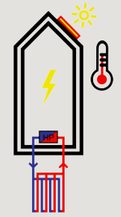


Fig. 72: Clusters inside buurt 3

PRINCIPLES	STEPS AND FEATURES	RESULTS
0. EXISTING SITUATION 	Features: • 45 multistory dwellings of social rental • poor energy performance	Heat demand H 15430 MWh/y CO2 3124 tCO2eq/y
1. DEMAND REDUCTION 	Insulation: • roof, walls, roofs • high performance windows Installation efficiency: • Smart appliances • change heating system • efficient mechinical ventilation with heat recovery • shower heat exchangers	Remaining heat demand H 3858 MWh/y CO2 781 tCO2eq/y
2. HEAT PRODUCTION 	• Transition to All-electric energy system • Individual GSHP with horizontal heat exchanger • Heat pump is used with GSHP system_the electricity used is produced by renewable sources	Remaining heat demand & Electricity demand for heat pump with COP = 6 H 0 MWh/y CO2 0 tCO2eq/y E 643 MWh/y
3. ELECTRICITY PRODUCTION 	PV on roofs: • 25 m2 per roof	Remaining heat & Electricity demand H 0 MWh/y E -21 MWh/y

Template 2: Description of measure used in steps leading to 2050 vision for cluster 3 in buurt 3

E=A*r*H*PR

Orientation		South	South-East	South-West
A (toral PV area m2)				1125
r (solar panel yield %)	0.8			
H (annual average irradiation m2 kWh/m2/year)		1180	820	820
PR (performance ratio 0.9-0.5)	0.9			
E (energy produced by the PV panel kWh)				664200

Table 11: Electricity production be PV panels on roofs

Buurt 2

Buurt 2 guides to a unified solution for the heat system selection and application, of creating a Small-scale heat network and using ATES system for heat and cold seasonal storage, since this neighbourhood includes only multi-storey dwellings that belong to big housing corporations.

Connection to Small-scale heat network with ATES system

The existing situation of the neighbourhood is characterised by a total of 22 multi-storey building blocks of social rental with heat demand of 12289 MWh/year and CO2 emissions of 2488 tCO2eq/year. In the next step, there is decrease of 75%, leading to 3072 MWh/year and 622 tCO2eq/year for heat demand and CO2 emissions respectively. In step 2 regarding the heat system, a Small-scale heat network is created to provide the dwellings with the excess heat from offices and supermarkets inside the neighbourhood. The heat is stored in an ATES system, as well as the cold, and are both used in seasonal mode. Finally, in step 3, 40 m2 of PV panels on each roof result in the production of 520 MWh/year, exceeding the heat pumps' demand by 8 MWh/year.

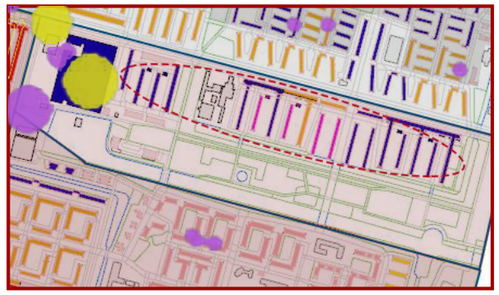
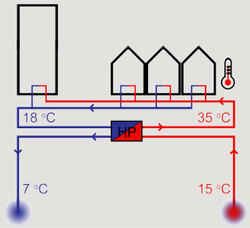


Fig. 73: Buurt 2

PRINCIPLES	STEPS AND FEATURES	RESULTS
0. EXISTING SITUATION 	Features: • 22 multistory building blocks of social rental • poor energy performance	Heat demand H 12289 MWh/y CO2 2488 tCO2eq/y
1. DEMAND REDUCTION 	Insulation: • roof, walls, roofs • high performance windows Installation efficiency: • Smart appliances • change heating system • efficient mechinical ventilation with heat recovery • shower heat exchangers	Remaining heat demand H 3072 MWh/y CO2 622 tCO2eq/y
2. HEAT PRODUCTION 	• Local heat network • Collective ATES using waste heat from offices and supermarkets • SC if heat demand is not covered • Heat pump is used with ATES system_the electricity used is produced by renewable sources	Remaining heat demand & Electricity demand for heat pump with COP = 6 H 0 MWh/y CO2 0 tCO2eq/y E 512 MWh/y
3. ELECTRICITY PRODUCTION 	PV on roofs: • 40 m2 per roof	Remaining heat & Electricity demand H 0 MWh/y CO2 0 tCO2eq/y E -8 MWh/y

Template 3: Description of measure used in steps leading to 2050 vision for buurt 2

E=A*r*H*PR

Orientation		South	South-East	South-West
A (toral PV area m2)				880
r (solar panel yield %)	0.8			
H (annual average irradiation m2 kWh/m2/year)		1180	820	820
PR (performance ratio 0.9-0.5)	0.9			
E (energy produced by the PV panel kWh)				519552

Table 12: Electricity production be PV panels on roofs

Buurt 4 Oost

In Buurt 4 Oost there are two proposed basic energy systems for 3 different clusters inside this neighbourhood. The following template represents the connection of the buildings in cluster 1 to the DHN and it is the last case described in this report.

Connection to the DHN for cluster 1

In step 0 of describing the existing situation of the neighbourhood, it is stated that the most suitable dwellings for connection to heat grid are 35 multi-storey building blocks of social rental with poor energy performance. Their total heat demand is 10899 MWh/year with CO2 emissions of 2206 tCO-2eq/year. In the case of using the DHN, the application of retrofit measures is not required before the connection to the heat system. A big amount of heat demand is needed for proceeding to an advantageous agreement for the energy suppliers as well, because otherwise they might not be willing to cooperate. Therefore, in step 2 the connection to the heat grid fulfills immediately the heat demand but the CO2 emissions are reduced by 50% since through the heat production from waste incineration process, CO2 is still emitted in the air. In order to reduce the emissions even more, retrofit measures are applied according to the goal of minimizing the need for heating by 75%. It is noteworthy to mention that there is a high possibility of eliminating the use of waste for providing the network with heat until 2050, assuming that the heat in the future will be provided by technologies using only sustainable sources like deep geothermal and solar collectors (sub-section 5.3.1). Thus, in 2020 the emissions can reach the value of 278 tCO2eq/year, and until 2050 it can be decreased to 0 tCO2eq/year.

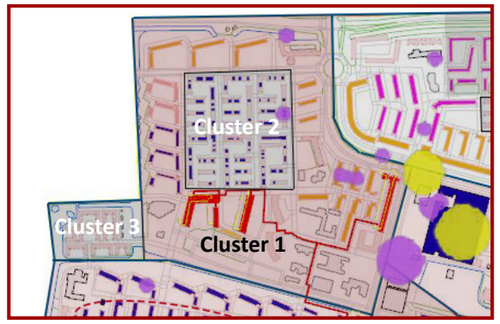
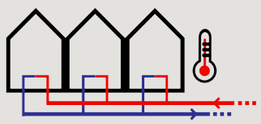


Fig. 74: Clusters inside buurt 4 oost

PRINCIPLES	STEPS AND FEATURES	RESULTS
0. EXISTING SITUATION 	Features: • 35 multistory building blocks of social rental • poor energy performance	Heat demand H 10899 MWh/y CO2 2206 tCO2eq/y
1. HEAT PRODUCTION 	• Collective District Heat Network is used	Remaining heat demand H 0 MWh/y CO2 1103 tCO2eq/y
2. DEMAND REDUCTION 	Insulation: • roof, walls, roofs • high performance windows Installation efficiency: • Smart appliances • change heating system • efficient mechinical ventilation with heat recovery • shower heat exchangers	Remaining heat demand H 0 MWh/y CO2 278 -> 0 tCO2eq/y Year 2020 -> 2050

Template 4: Description of measure used in steps leading to 2050 vision for cluster 1 inside buurt 4 oost

7.3 DEFINE INTERVENTIONS ON TIMELINE

The current sub-section, of defining the interventions on timeline, starting from today until 2050, constitutes the last part of the roadmap design. After deciding the suitable energy systems for the clusters inside each neighbourhood, the building blocks are prioritised with the use of the decision-making diagram once again, based on their heat demand levels. The retrofit interventions are in stages of 5-year periods, except for the first time referring to the period between 2017 until 2020, since the application of retrofit measures in steps results a more economic path for the owners. The heat demands of all dwellings are examined every 5 years to go first for retrofit for the buildings exceeding the set heat-demand limit, until the demand is reduced by 75% according to the specific goal for these neighbourhoods (see sub-section 6.2.1).

The mentioned heat demand limit changes after each 5-year period of retrofit interventions, following the decrease in the dwellings' demands, starting from 300 kWh/m2 in 2017, dropping to 250 kWh/m2 in 2020, to 200 kWh/m2 in 2025, 150 kWh/m2 in 2030, 100 kWh/m2 in 2035, and finally, all building blocks' demand should be below 100 kWh/m2 for the last decade until 2050. The energy need for heating for each building block individually is retrieved from the context analysis (Appendix). For visualising the changes in heat demand 3-dimensional heat maps are designed, showing firstly the buildings chosen to be retrofitted the specific 5-year period, and secondly the reduced heat demand values by retrofit stages and the covered values by renewable sources.

Retrofit is in 3 stages, following defined renovation stages of the project Europe's Buildings under the Microscope considering the minor retrofit results in 30% energy savings, moderate retrofit results in 30%-60% energy savings, and deep retrofit in 60%-90% savings. In the visualisations illustrated below, the average percentage of each stage is taken into account, guiding to the final step of 75% energy reduction for the selected neighbourhoods for retrofit interventions, and in final stage, in vision for 2050, all heat demands should be covered by the use of renewable energy systems.

2017 - 2020

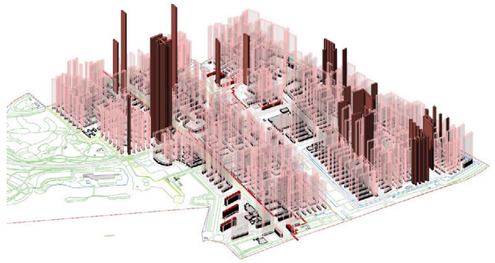


Fig. 73: Selected buildings for retrofit in period 2017-2020

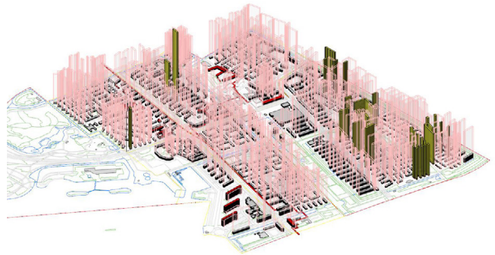


Fig. 74: Reduced demand of several dwellings from retrofit measures and covered demand in case of connection to the DHN, 2020

At 2017, the buildings from each neighbourhood with heat demand higher than 300 kWh/m2 are picked for retrofit interventions until 2020, which are visible in the first diagram of the initial heat demand levels. By following the first sub-step of the roadmap design, through which the suitable energy systems matching each cluster inside these neighbourhoods are decided (sub-chapter 7.1), some of the selected buildings are directly connected to the DHN and the rest go for the first stage of retrofit. The second graph, represents the situation in 2020, after the first retrofit interventions. The connected dwellings to the DHN are shown in red colour, and their heat demand is not visible anymore since it is covered fully from the heat grid that uses HT renewable energy sources. Also, the heat demand of the rest of the dwellings after minor retrofit, is shown in yellow colour with 15% demand reduction.

2020 - 2025

Fig. 75: Selected buildings for retrofit in period 2020-2025

Fig. 76: Reduced demand of several dwellings from retrofit measures and covered demand in case of connection to the DHN, 2025

At 2020, through the second application of the decision-making diagram on the area, the buildings with demand higher than 250 kWh/m2 are chosen to be retrofitted until 2025 (figure 75). Some of them are connected to DHN, some are getting minor retrofit measures, illustrated in the same way as in the previous example, and some are getting moderate retrofit measures, resulting to 45% demand reduction shown in blue colour, since they got minor retrofit the previous 3 years (figure 76).

2025 - 2030

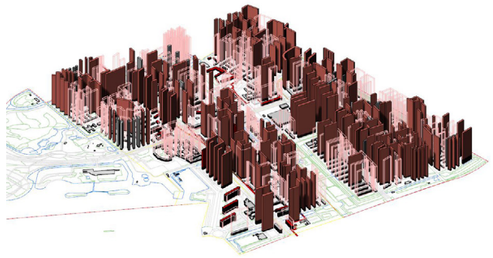


Fig. 77: Selected buildings for retrofit in period 2025-2030

Fig. 78: Reduced demand of several dwellings from retrofit measures and covered demand in case of connection to the DHN, 2030

For selecting the buildings for retrofit interventions through tis 5-year period, from the third application of the decision-making diagram in 2025, the limit is determined as 200 kWh/m2 (figure 77). In 2030, more dwellings are connected to DHN, others for minor retrofit with 15% decrease in heat demand, some are getting moderate retrofit achieving 45% demand reduction, and others for deep retrofit, as moderate retrofit measures are already applied on them in the previous 5 years, leading to the final goal of 75% demand reduction (figure 78).

2030 - 2035

Fig. 79: Selected buildings for retrofit in period 2030-2035

Fig. 80: Reduced demand of several dwellings from retrofit measures and covered demand in case of connection to the DHN, 2035

Same procedure is repeated for the dwellings exceeding the value of 150 kWh/m2.

2035 - 2040

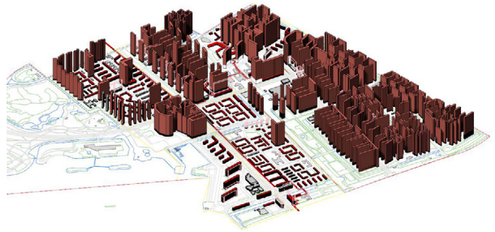


Fig. 81: Selected buildings for retrofit in period 2035-2040

Fig. 82: Reduced demand of several dwellings from retrofit measures and covered demand in case of connection to the DHN, 2040

Same procedure is repeated for the dwellings exceeding the value of 100 kWh/m2.

2040 - 2050

Fig. 83: Selected buildings for retrofit in period 2040-2050

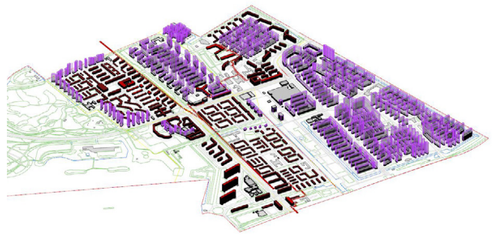
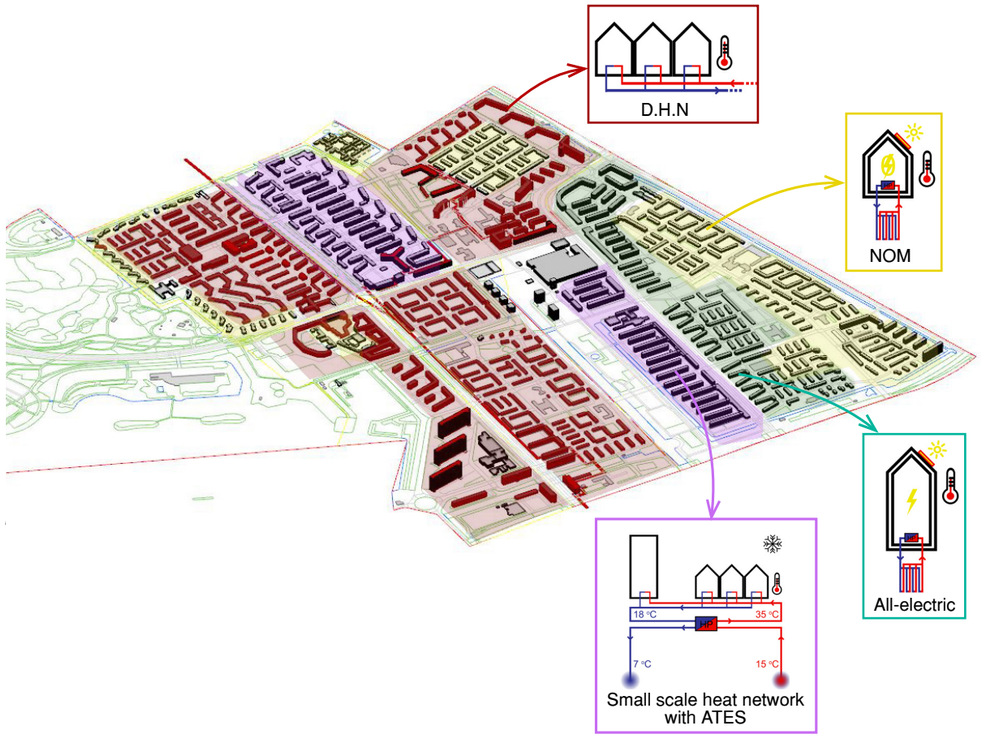


Fig. 84: Reduced demand of several dwellings from retrofit measures and covered demand in case of connection to the DHN, 2050

This procedure is repeated until the last decade before reaching 2050, when all dwellings' heat demand individually should be below 100 kWh/m2. The illustrated demands coloured in purple, are the remaining values to be covered by LT energy systems, in the specific clusters as already decided (recall sub-section 7.1), while the red building blocks' demands are already fulfilled by the use of the local DHN.

Implemented energy systems overview_ 2050 vision



This map expresses the final vision for 2050 as an overview of the applied energy systems on the selected neighbourhoods for retrofit interventions inside Amsterdam Nieuw West district. For reaching this vision, at the point that heat demand of all dwellings is covered by renewable sources, both of the 3 sub-steps of the roadmap have been unavoidable for realizing the suitable placements of each basic energy system, for quantifying the changes in heat demand of each dwelling, and for visualising these outcomes on timeline. Finally, it is remarkable to mention that even though in reality the LT systems will not be applied in 2050, the graphs showing the process in time, aim to illustrate the demand changes due to the retrofit stages, required before applying the systems.

08

CONCLUSIONS

Under the aim of creating more sustainable cities, different and complex methods to define sustainable measures, actions and interventions are usually used. Amsterdam is one of the cities that intend to become climate friendly and energy efficient until 2050 and totally independent of fossil fuels in later plans. The European City-zen project points at the development of an energy transition urban planning methodology for fully sustainable and energy (carbon) neutral smart cities in the future, by using Amsterdam as one of the case studies (Broersma & Fremouw, 2015). This chapter presents the thesis conclusions by answering first the research question, and by discussing furthermore the main outcomes of this research. By answering the research question, this thesis research aims to contribute in the City-Zen project.

Research question

Which is the methodology leading to the design of a roadmap that helps to define which energy systems and retrofit measures should be applied where and when, on residential neighbourhoods of Amsterdam Nieuw West until 2050, for achieving their energy transition and CO2 emissions reduction?

The answer to that question is given by implementing a 4-step energy urban planning methodology that facilitates the realization of a roadmap design, that in combination with a set of energy and retrofit measures, as well as basic data which was extracted from the context analysis, suitable energy systems and retrofit measures applications on residential neighbourhoods of Amsterdam Nieuw West can be determined. This roadmap is a useful tool for Amsterdam Municipality, that consists of an overview regarding the context and energy conditions, for the sake of providing with more unified solutions of energy systems and retrofit measures, for clusters of dwellings with the same construction and ownership traits, consisting the different neighbourhoods.

The 4 steps of the methodology, to be implemented respectively, start from 1) map the present, 2) define the future energy targets, 3) develop the strategy for selecting suitable energy systems, and finally 4) the design of the energy transition roadmap for selected neighbourhoods inside Amsterdam Nieuw West district. By following the aforementioned steps on both city and neighbourhood scale results in the realization of an energy transition roadmap. This roadmap aims to satisfy the requirements and the goals that were defined in the running scenario with 60% reduction for the entire city of Amsterdam and up to 75% reduction for Amsterdam Nieuw West district by 2050.

Nevertheless, the first step for applying the methodology steps, is to define the energy goals which were set to a 60% decrease of the total heat demand (for heating space and DHW). By assuming that in some districts the demand is going to have less reduction, like in the case of the Center that has a high heat density and the intervention restrictions regarding the historical buildings do not allow as much reduction as desired. Thus, a higher goal has been set for Amsterdam Nieuw West, pursuing 75% decrease in heat demand. The selected neighbourhoods for retrofit interventions inside Amsterdam Nieuw West district follow the same goal. Moreover, by taking as a fact that in 2050 natural gas is no longer used in Amsterdam city according to the municipality's goals, a significant decrease of the respective CO2 emissions is expected (i.e. take it for granted). An additional assumption is that the electricity need of dwellings remains the same as today, as it can be reduced by using smart-appliances in dwellings, while more heat pumps are going to be used that need electricity to operate.

Moreover, a scenario is developed concerning the 2050 availability of LT and HT heat for fulfilling the future heat demand that leads to a proposal of LT and HT heat systems ratio in each district. Since the current gas demand of the city is known, the current energy demand for heating space and for DHW is calculated as 25 PJ, by assuming that 90% efficiency boilers are used. Nonetheless, a more thorough inspection regarding the exact efficiency of gas boilers is required for the sake of achieving more accurate results of the heat demand. Since potential sources availability is known as well, showing that more LT heat (22.3 PJ) comparing to DHN heat (9-12 PJ) will be offered to cover the future heat demand of 10 PJ. A main conclusion of this scenario is that in 2050 the heat demand and the electricity need for operating the systems can be fully covered by renewable sources.

By taking into account the current energy potentials and the existing scenarios of energy systems applications, basic energy systems could be classified as suitable for neighbourhoods of Amsterdam. The classified energy systems are 1) the DHN, 2) small-scale heat network connected to ATES system, 3) the transition to All-electric and 4) NOM. Green gas is another proposed system but it is excluded because of the small amount of available biomass.

The final outcome of the roadmap consists of 3 sub-steps which are 1) the selection of suitable energy systems for 2050 for each one of the selected neighbourhoods, 2) the description of the energy system and retrofit measures, and the corresponding changes in heat demand and CO2 emissions are listed in templates, and 3) the definition of the interventions determined by the 2 previous sub-steps on timeline, starting from today and ending in 2050.

Sub-step 1 is achieved by applying a developed decision-making diagram, concentrating the main variables, revealed from literature review, that helps in decision making for selecting the suitable energy systems among the classified ones. These variables concern mainly the ownership status, the number of storeys of each building block, the availability of excess heat from non-residential buildings inside a neighbourhood, and the possible existence of the DHN in a neighbourhood. The variable regarding the balance of heating and cooling demand of a neighbourhood through the year is mentioned since it is essential for using ATES system. However, the cooling demand could not be found to make this comparison.

Due to the different features which derived from each building block it has pointed out that not all buildings inside a neighbourhood share similar set of variables. Thus, the collected data regarding the typology, ownership and energy characteristics of each building block, contributed in selecting systems for small clusters of dwellings with similar construction characteristics and ownership status, leading to variations inside several neighbourhoods. For instance, dwellings of social rental (one owner) and dwellings of private ownership (multiple owners), shape different clusters even if they are in the same neighbourhood. Also, the ownership status results the starting variable for the decision-making, since if there is one owner for a building block of social rental, leads to collective

solutions, like the connection to DHN or to Small-scale heat network connected to ATES. Otherwise, individual solutions are possible, such as the transition of the building to All-electric or NOM.

A building block of multiple owners can still be connected to collective heat networks, yet in this decision-making process it is simpler to assume that the collective solutions are proposed for buildings of only one owner since it is easier to be convinced. For more detailed and reliable results, proceeding with interviews of both the home owners and energy suppliers of the DHN would be crucial, because the heat demand should be high enough for ending up in an advantageous agreement for both sides. Also, in reality the transition to NOM is possible for 3-storey building blocks in some cases, but in this project it is considered as a solution for 2-storey buildings to simplify the process, since their roof area offered for energy production technologies can certainly cover the energy needs of the house.

In the second stage of the roadmap design, description templates are provided, one for each energy system, listing the used energy retrofit measures in steps, and quantifying the changes in heat demand and in CO2 emissions according to each step until the demands are fully covered by renewable sources. In these templates, the electricity use is only considered to be balanced for the heat pumps used when LT heat systems are implemented. The heat production by individual applications of GSHP, in the cases of describing the All-electric and NOM energy systems, is just a choice among several others. Solar collectors can be used or PVTs if more heat is needed. In the case of Small-scale heat network with ATES, the heat is collected from non-residential buildings but LT from PVTs can be stored as well. Electricity is produced by PVs' installations per roof, and the number of panels is calculated for fulfilling the heat pumps demand. When the produced electricity exceeds the heat pumps' demand, it can be used for user-related purposes. When DHN is used, the heat demand of the connected dwellings is covered, and it is the only case that demand reduction is not required before applying the energy system. Also, heat pumps are not needed since the due to the provided high temperature heat from the heat grid.

For the third stage of the roadmap design, the collected retrofit solutions from the first two substeps are used for defining the interventions on timeline. The changes in heat demand are visualised on 3-dimensional heat maps, showing the results of 5-year periods of retrofit actions, starting from today until reaching the final energy goal of 75% decrease in heat demand by 2050. The remaining heat demands can be covered by implementing the classified energy systems using local renewable sources. The dwellings are prioritised for intervention based on their individual heat demand levels in order to complete their retrofit in stages, resulting in a more economical path. These heat maps are a useful visualization tool that can help the municipality and the stakeholders realize how the different measures affect the heat demand through the years.

A final 3-dimensional map of the area in the end of the roadmap process illustrates all the proposed results, forming the energy systems 2050 vision for the specific neighbourhoods. These results cannot be presented as fixed solutions, due to the fact that the technologies and the availability of renewable sources may undergo changes that cannot be predicted precisely over a period of 33 years from today. In addition, stakeholders play a dominant role on the decision-making for selecting systems, and further research is required, such as interviewing the owners and asking the energy suppliers about future plans, for giving more detailed and accurate solutions. Last but not least, the developed energy urban planning methodology steps leading to the energy transition roadmap design, can be definitely used in other neighbourhoods of Amsterdam, and results a promising methodology for further implementations in other cities of the world, serving the targets of the largest society to decrease CO2 emissions and achieve the desired sustainable development. Nevertheless, several alterations are needed for using it in other places of different context and energy characteristics. These alterations can be based on different future energy goals of other cities, and on the local demands and potentials that must be collected. All this data will probably lead to the classification of different basic energy systems, guiding to different application variables for the decision-making process of selecting suitable energy systems for clusters of dwellings on the appropriate time.

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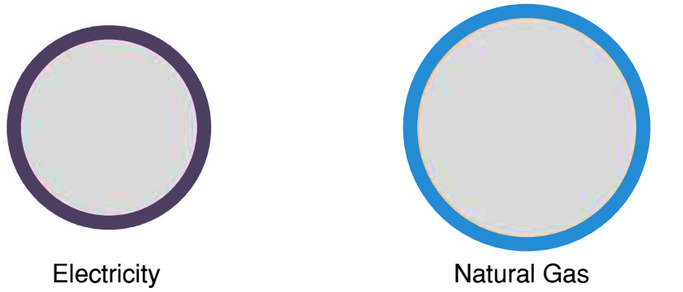
APPENDIX

Energy demands calculation_conversion of electricity and natural gas amounts to PJ per year



Energy potentials calculation_excel template

Renewable heat sources	Potentials
Deep geothermal	4.00
Rest heat from waste incineration	2.00
Solar collectors	3.00
Biomass	0.06
Rest heat from buildings	1.90
Solar heat from PVTs	12.00
GSHP	8.40
Total amount	**31.36**

Renewable electricity sources	Potentials
Biomass	0.06
Sun (Pv on roofs)	4.01
Wind	1.78
Domestic waste	1.18
Total amount	**7.03**

CO2 emissions calculation_conversion of natural gas amount to CO2

1 m3 natural gas = 1.78 kg CO2

1 tCO2eq = 1 tonne, where tCO2eq is the unit of measure for atmospheric pollution

Data extraction through site analysis

Area	Neighbourhood	Building block number	House typology	Additional classification	Year of construction	Storeys number	Type of roof	Use surface m2	Gas consumption m3	Gas m3/m2	Gas CO2 emmisions kg	Gas consumption kWh	Heat demand kWh	Heat demand kWh/m2
Slotermeer-Zuidwest	Buurt 5 Noord	18197	Apartment blocks	Portiekflat	1954	4	Flat	1298	23940	18	42613	233870	210483	162
		22459	Rowhouses		1954	2	Saltbox	204	5123	25	9119	50047	45042	221
		18193	Apartment blocks	Portiekflat	1954	4	Flat	1424	26638	19	47416	260227	234204	164
		22461	Rowhouses		1954	2	Saltbox	204	5156	25	9178	50369	45332	222
		18231	Apartment blocks	Portiekflat	1954	4	Flat	1298	25020	19	44536	244420	219978	169
		22461_	Rowhouses		1954	2	Saltbox	204	5156	25	9178	50369	45332	222
		18232	Apartment blocks	Portiekflat	1954	4	Flat	1298	27100	21	48238	264740	238266	184
		22460	Rowhouses		1954	2	Saltbox	204	4652	23	8281	45445	40901	200
		18230	Apartment blocks	Portiekflat	1954	4	Flat	1298	25640	20	45639	250477	225429	174
		22460_	Rowhouses		1954	2	Saltbox	204	4652	23	8281	45445	40901	200
		18233	Apartment blocks	Portiekflat	1954	4	Flat	1298	28640	22	50979	279784	251806	194
		22460__	Rowhouses		1954	2	Saltbox	204	4652	23	8281	45445	40901	200
		17950	Rowhouses		1954	3	Gable	469	8295	18	14765	81034	72930	156
		18755	Apartment blocks	Portiekflat	1954	4	Flat	5127	89205	17	158785	871444	784299	153
		22942	Appartment blocks	Gallerijflat	1954	5	Flat	5507	284985	52	507273	2784018	2505617	455
		18575	Appartment blocks	Portiekflat	1990	4	Flat	4230	46540	11	82841	454649	409184	97
		18454	Rowhouses		1990	2	Saltbox	686	8169	12	14541	79803	71823	105
		18952	Rowhouses		1990	2	Saltbox	1322	13026	10	23186	127251	114526	87
		18712	Apartment blocks	Portiekflat	1954	6	Gable	2913	53862	18	95874	526178	473560	163
		18713	Apartment blocks	Portiekflat	1954	6	Gable	3033	50520	17	89926	493530	444177	146
		18990	Apartment blocks	Portiekflat	1954	6	Gable	3606	61366	17	109231	599484	539536	150
		18864	Apartment blocks	Portiekflat	1954	6	Gable	3643	62769	17	111729	613190	551871	151
		18806	Apartment blocks	Portiekflat	1954	6	Gable	3029	48557	16	86431	474353	426918	141
		18991	Apartment blocks	Portiekflat	1954	6	Gable	2922	58416	20	103980	570666	513599	176
		18935	Apartment blocks	Portiekflat	1954	6	Gable	2784	49632	18	88345	484855	436370	157
		19030	Apartment blocks	Portiekflat	1954	6	Gable	2924	52800	18	93984	515803	464223	159
		18961	Apartment blocks	Portiekflat	1954	6	Gable	2784	52704	19	93813	514865	463379	166
		19029	Apartment blocks	Portiekflat	1954	6	Gable	2883	54432	19	96889	531746	478572	166
		18959	Apartment blocks	Portiekflat	1954	6	Gable	2784	43056	15	76640	420614	378553	136
		18841	Appartment blocks	Gallerijflat	1956	5	Flat	6077	25476	4	45347	248875	223988	37
		18170	Rowhouses		1954	1	Shed	784	13275	17	23630	129683	116715	149
		18995	Apartment blocks	Portiekflat	1954	5	Open Gable	2951	71778	24	127765	701199	631079	214
		18823	Apartment blocks	Portiekflat	1954	5	Open Gable	2339	48622	21	86547	474988	427489	183
		18007	Rowhouses		1954	1	Shed	372	11598	31	20644	113301	101971	274
		18237	Rowhouses		1954	1	Shed	366	24468	67	43553	239028	215125	588
		18236	Rowhouses		1954	1	Shed	368	9300	25	16554	90852	81767	222
		18738	Rowhouses		1954	1	Shed	497	11128	22	19808	108709	97838	197
		18161	Apartment blocks	Portiekflat	1954	5	Gable	1413	10746	8	19128	104978	94480	67
		18161_	Apartment blocks	Portiekflat	1954	5	Gable	1178	9708	8	17280	94837	85354	72
		18169	Apartment blocks	Portiekflat	1954	5	Gable	1307	8670	7	15433	84697	76228	58
		18994	Appartment blocks	Gallerijflat	1961	5	Flat	4315	33511	8	59650	327369	294632	68
		18015	Apartment blocks	Portiekflat	1954	5	Gable	1066	8490	8	15112	82939	74645	70
		18360	Apartment blocks	Portiekflat	1954	5	Gable	1287	10150	8	18067	99155	89240	69
		18318	Apartment blocks	Portiekflat	1954	5	Gable	1067	9468	9	16853	92493	83244	78
		18360_	Apartment blocks	Portiekflat	1954	5	Gable	1314	14498	11	25806	141631	127468	97
		18318_	Apartment blocks	Portiekflat	1954	5	Gable	1067	8979	8	15983	87716	78944	74
		18361	Apartment blocks	Portiekflat	1954	5	Gable	1257	18846	15	33546	184107	165696	132
		18318__	Apartment blocks	Portiekflat	1954	5	Gable	1067	8979	8	15983	87716	78944	74
		18167	Apartment blocks	Portiekflat	1954	5	Gable	1307	14715	11	26193	143751	129376	99
		19123	Appartment blocks	Gallerijflat	1956	5	Flat	4315	61980	14	110324	605483	544934	126
		18353	Rowhouses		1953	3	Gable	512	10368	20	18455	101285	91156	178
		18354	Rowhouses		1954	3	Gable	512	13544	26	24108	132311	119080	233
		18434	Rowhouses		1954	3	Gable	512	10160	20	18085	99253	89328	174
		18435	Rowhouses		1954	3	Gable	516	10608	21	18882	103630	93267	181
		18399	Rowhouses		1954	3	Gable	512	9528	19	16960	93079	83771	164
		18398	Rowhouses		1954	3	Gable	512	12176	24	21673	118947	107053	209
		16772	Rowhouses		1954	3	Gable	512	10848	21	19309	105974	95377	186
											3090650		15265899	

Area	Neighbourhood	Building block number	House typology	Additional classification	Year of construction	Storeys number	Type of roof	Use surface m2	Gas consumption m3	Gas m3/m2	Gas CO2 emmisions kg	Gas consumption kWh	Heat demand kWh	Heat demand kWh/m2
Slotermeer-Zuidwest	Buurt 4 Oost	18937	Appartment blocks	Portiekflat	1955	5	sloped	2804	59808	21	106458	584264	525838	188
		18938	Appartment blocks	Portiekflat	1955	5	sloped	2804	55056	20	98000	537842	484058	173
		18939	Appartment blocks	Portiekflat	1955	5	sloped	2804	58703	21	104491	573470	516123	184
		19067	Appartment blocks	Gallerijflat	1959	9	flat	6498	146382	23	260560	1430006	1287005	198
		19082	Multifamily house		1955	3	sloped	1048	21462	20	38202	209662	188696	180
		19081	Multifamily house		1955	3	sloped	1048	23380	22	41616	228399	205559	196
		18596	Multifamily house		1955	3	sloped	1048	21420	20	38128	209252	188327	180
		18631	Multifamily house		1955	3	sloped	1048	25340	24	45105	247546	222792	213
		18594	Multifamily house		1955	3	sloped	1048	26208	25	46650	256026	230423	220
		18001	Multifamily house		1955	2	sloped	472	12096	26	21531	118166	106349	225
		11019	Multifamily house		1955	2	sloped	472	10664	23	18982	104177	93759	199
		13194	Multifamily house		1955	2	sloped	472	10392	22	18498	101519	91368	194
		17970	Multifamily house		1955	2	sloped	472	10184	22	18128	99487	89539	190
		17971	Multifamily house		1955	2	sloped	472	9304	20	16561	90891	81802	173
		18275	Appartment blocks	Portiekflat	1954	5	sloped	1380	29400	21	52332	287209	258488	187
		18087	Appartment blocks	Portiekflat	1954	5	sloped	1380	28248	20	50281	275955	248359	180
		18088	Appartment blocks	Portiekflat	1954	5	sloped	1380	27528	20	49000	268921	242029	175
		18572	Appartment blocks	Gallerijflat	1958	9	flat	4594	15375	3	27368	150198	135179	29
		18315	Multifamily house		1962	2	flat	578	17484	30	31122	170801	153721	266
		12617	Appartment blocks	Gallerijflat	2009	3	flat	4591	0	0	0	0	0	0
		6066	Appartment blocks	Gallerijflat	2009	3	flat	1044	0	0	0	0	0	0
		12641	Appartment blocks	Gallerijflat	2009	3	flat	2814	0	0	0	0	0	0
		18774	Appartment blocks	Gallerijflat	1997	7	flat	4512	51504	11	91677	503143	452828	100
		18775	Appartment blocks	Gallerijflat	1997	7	flat	4512	46416	10	82620	453438	408094	90
		18923	Appartment blocks	Portiekflat	1954	5	sloped	1812	37576	21	66885	367080	330372	182
		18925	Appartment blocks	Portiekflat	1954	5	sloped	1812	35952	20	63995	351215	316094	174
		19086	Appartment blocks	Portiekflat	1954	5	sloped	1822	35056	19	62400	342462	308216	169
		18610	Appartment blocks	Portiekflat	1954	5	sloped	3178	47040	15	83731	459534	413580	130
		18113	Appartment blocks	Portiekflat	1954	5	sloped	1168	21420	18	38128	209252	188327	161
		18960	Appartment blocks	Portiekflat	1954	5	sloped	3914	75468	19	134333	737247	663522	170
		18541	Appartment blocks	Portiekflat	1954	5	sloped	1169	28033	24	49899	273854	246469	211
		18726	Appartment blocks	Portiekflat	1958	5	flat	9622	121968	13	217103	1191505	1072355	111
		11014	Appartment blocks	Portiekflat	2005	8	flat	8975	130848	15	232909	1278254	1150429	128
											Total		Total	
											2206693		10899698	
		18638	Rowhouses		1954	2	sloped	1199	24000	20	42720	234456	211010	176
		18637	Rowhouses		1954	2	sloped	1193	22736	19	40470	222108	199897	168
		18639	Rowhouses		1954	2	sloped	1223	20576	17	36625	201007	180906	148
		18773	Rowhouses		1954	2	sloped	1277	27455	21	48870	268208	241387	189
		18743	Rowhouses		1954	2	sloped	1284	25056	20	44600	244772	220295	172
		18590	Rowhouses		1955	2	sloped	1090	24784	23	44116	242115	217903	200
		18934	Rowhouses		1954	2	sloped	1461	27056	19	48160	264310	237879	163
		18933	Rowhouses		1954	2	sloped	1466	30020	20	53436	293265	263939	180
		18931	Rowhouses		1954	2	sloped	1430	25498	18	45386	249090	224181	157
		18772	Rowhouses		1954	2	sloped	1378	24038	17	42788	234827	211344	153
		18771	Rowhouses		1954	2	sloped	1440	28386	20	50527	277303	249573	173
		18997	Rowhouses		1955	2	sloped	2313	40068	17	71321	391424	352282	152
		17961	Rowhouses		1954	2	sloped	608	13488	22	24009	131764	118588	195
		18417	Rowhouses		1954	2	sloped	629	9912	16	17643	96830	87147	139
		18494	Rowhouses		1954	2	sloped	635	9536	15	16974	93157	83841	132
		17960	Rowhouses		1954	2	sloped	590	12544	21	22328	122542	110288	187
		18416	Rowhouses		1954	2	sloped	536	9120	17	16234	89093	80184	150
		18492	Rowhouses		1954	2	sloped	590	12840	22	22855	125434	112891	191
		17959	Rowhouses		1954	2	sloped	608	11688	19	20805	114180	102762	169
		18418	Rowhouses		1954	2	sloped	599	10944	18	19480	106912	96221	161
		18493	Rowhouses		1954	2	sloped	608	10608	17	18882	103630	93267	153
		18453	Rowhouses		1954	2	sloped	608	10472	17	18640	102301	92071	151
		18489	Rowhouses		1954	2	sloped	599	11008	18	19594	107537	96783	162
		18450	Rowhouses		1954	2	sloped	594	11088	19	19737	108319	97487	164
		18452	Rowhouses		1954	2	sloped	608	11936	20	21246	116603	104943	173
		18490	Rowhouses		1954	2	sloped	608	10616	17	18896	103708	93337	154
		18449	Rowhouses		1954	2	sloped	608	9416	15	16760	91985	82786	136
		18565	Rowhouses		1955	2	sloped	599	11328	19	20164	110663	99597	166
		18527	Rowhouses		1955	2	sloped	599	20164	34	35892	196980	177282	296
		18208	Rowhouses		1988	2	flat	712	11608	16	20662	113399	102059	143
		18891	Rowhouses		1989	2	flat	1030	17664	17	31442	172560	155304	151
		18928	Rowhouses		1989	2	flat	1030	16944	16	30160	165526	148973	145
		19013	Rowhouses		1989	2	flat	864	12170	14	21663	118889	107000	124
		19010	Rowhouses		1989	2	flat	853	11790	14	20986	115177	103659	122
		19012	Rowhouses		1988	2	flat	864	13440	16	23923	131295	118166	137
		19011	Rowhouses		1988	2	flat	864	13170	15	23443	128658	115792	134
		18319	Rowhouses		1988	2	flat	698	12928	19	23012	126294	113664	163
											Total		Total	
											1114449		5504688	

Area	Neighbourhood	Building block number	House typology	Additional classification	Year of construction	Storeys number	Type of roof	Use surface m2	Gas consumption m3	Gas m3/m2	Gas CO2 emmisions kg	Gas consumption kWh	Heat demand kWh	Heat demand kWh/m2
Slotermeer-Zuidwest	Buurt 5 Zuid	8564	Apartment blocks	Portiekflat	1955	4	Open Gable	1262	24915	20	44349	243395	219055	174
		13191	Apartment blocks	Portiekflat	1955	4	Open Gable	836	15060	18	26807	147121	132409	158
		16757	Apartment blocks	Portiekflat	1955	4	Open Gable	1261	33084	26	58890	323198	290878	231
		19365	Apartment blocks	Portiekflat	1955	4	Open Gable	941	19035	20	33882	185953	167358	178
		15972	Apartment blocks	Portiekflat	1955	5	Open Gable	2098	38656	18	68808	377630	339867	162
		15502	Apartment blocks	Portiekflat	1955	5	Open Gable	1863	37240	20	66287	363798	327418	176
		15947	Apartment blocks	Portiekflat	1954	4	Open Gable	1261	29196	23	51969	285216	256694	204
		16102	Apartment blocks	Portiekflat	1955	4	Open Gable	944	19045	20	33900	186051	167446	177
		16005	Apartment blocks	Portiekflat	1954	4	Open Gable	1261	30420	24	54148	297173	267456	212
		16105	Apartment blocks	Portiekflat	1955	4	Open Gable	944	20846	22	37106	203645	183280	194
		15946	Apartment blocks	Portiekflat	1954	4	Open Gable	1261	32976	26	58697	322143	289928	230
		15419	Apartment blocks	Portiekflat	1954	4	Open Gable	832	19056	23	33920	186158	167542	201
		15945	Apartment blocks	Portiekflat	1954	4	Open Gable	1261	30056	24	53500	293617	264255	210
		13169	Apartment blocks	Portiekflat	1954	4	Open Gable	946	22095	23	39329	215846	194261	205
		15668	Apartment blocks	Portiekflat	1954	4	Open Gable	1261	29844	24	53122	291546	262391	208
		15328	Rowhouses		1955	1	Open Gable	233	8064	35	14354	78777	70899	304
		15119	Rowhouses		1955	1	Open Gable	240	14064	59	25034	137391	123652	515
		15539	Multifamily house		2009	4	Saltbox	801	0	0	0	0	0	0
		11864	Multifamily house		2009	4	Saltbox	801		0	0	0	0	0
		11926	Multifamily house		2009	4	Saltbox	801		0	0	0	0	0
		22282	Semi- detached house		1955	2	Flat	204	3906	19	6953	38158	34342	168
		16307	Apartment blocks	Portiekflat	1956	5	Flat	4684	105612	23	187989	1031724	928551	198
		20183	Apartment blocks	Portiekflat	1954	5	Open Gable	3047	42228	14	75166	412525	371273	122
		20183_	Apartment blocks	Portiekflat	2007	5	Flat	3100	0	0	0	0	0	0
		15542	Apartment blocks	Portiekflat	2007		Flat	2675	0	0	0	0	0	0
		15541	Rowhouses		2009	3	Open Gable	2022	0	0	0	0	0	0
		15540	Rowhouses		2009	3	Open Gable	1506	0	0	0	0	0	0
		20874	Apartment blocks	Gallerijflat	1958		Flat	2540	32360	13	57601	316125	284512	112
		23493	Appartment blocks	Portiekflat	1958			15421	1034180	67	1840840	10102904	9092614	590
		22282_	Semi- detached house		1955	2	Flat	204	3906	19	6953	38158	34342	168
		16382	Rowhouses		1957	4	Open Gable	2972	47586	16	84703	464868	418381	141
		22282__	Semi- detached house		1955	2	Flat	204	3906	19	6953	38158	34342	168
		15814	Apartment blocks	Portiekflat	1955	5	Open Gable	1735	38528	22	68580	376380	338742	195
		15512	Apartment blocks	Portiekflat	1955	5	Open Gable	1959	38080	19	67782	372004	334803	171
		15866	Apartment blocks	Portiekflat	1955	5	Open Gable	1959	35280	18	62798	344650	310185	158
		15448	Apartment blocks	Portiekflat	1956	5	Open Gable	1752	36092	21	64244	352583	317324	181
		16623	Multifamily house		1956	6	Flat	3847	61544	16	109548	601223	541101	141
		16605	Multifamily house		1955	3	Dormer	1866	35616	19	63396	347933	313139	168
		16412	Multifamily house		1955	3	Dormer	2195	37120	17	66074	362625	326363	149
		16417	Multifamily house		1955	3	Dormer	2021	35190	17	62638	343771	309394	153
		23501	Semi- detached house		1956	2	Flat	2000	117565	59	209266	1148492	1033643	517
		22283	Semi- detached house		1955	2	Flat	204	4248	21	7561	41499	37349	183
		22283_	Semi- detached house		1955	3	Flat	195	4248	22	7561	41499	37349	192
		22283__	Semi- detached house		1954	2	Flat	195	4248	22	7561	41499	37349	192
		16454	Rowhouses		1955	2	Flat	2202	29638	13	52756	289534	260580	118
		19273	Rowhouses		1955	2	Flat	1106	17360	16	30901	169590	152631	138
		18777	Apartment blocks	Gallerijflat	2007	5	Flat	5642	0	0	0	0	0	0
		16301	Multifamily house		1955	3	Open Gable	1872	35280	19	62798	344650	310185	166
		16479	Multifamily house		1955	3	Open Gable	2128	44576	21	79345	435463	391917	184
		16044	Multifamily house		1955	3	Open Gable	1853	34074	18	60652	332869	299582	162
		22294	Semi- detached house		1955	3	Flat	335	7659	23	13633	74821	67339	201
		22294_	Semi- detached house		1955	3	Flat	335	7659	23	13633	74821	67339	201
		22284	Semi- detached house		1955	3	Flat	174	4738	27	8434	46286	41657	239
		22284_	Semi- detached house		1955	3	Flat	174	4738	27	8434	46286	41657	239
		15698	Rowhouses		1954	3	Open Gable	1034	18640	18	33179	182094	163885	158
		16149	Rowhouses		1954	3	Open Gable	1020	21296	21	37907	208041	187237	184
		15201	Rowhouses		1954	3	Open Gable	1017	21728	21	38676	212261	191035	188
		16404	Rowhouses		1995	3	Open Gable	3945	44720	11	79602	436870	393183	100
		16444	Multifamily house		1955	3	Open Gable	1755	33384	19	59424	326128	293515	167
		15526	Multifamily house		1955	3	Open Gable	1774	33384	19	59424	326128	293515	165
		15917	Multifamily house		1955	3	Open Gable	1511	24266	16	43193	237055	213349	141
		22293	Semi- detached house		1955	2	Flat	335	9294	28	16543	90793	81714	244
		22293_	Semi- detached house		1955	2	Flat	285	9294	33	16543	90793	81714	287
		22292	Semi- detached house		1955	2	Flat	285	10992	39	19566	107381	96643	339
		22284__	Semi- detached house		1955	2	Flat	174	4738	27	8434	46286	41657	239
		22285	Semi- detached house		1955	2	Flat	174	3442	20	6127	33625	30262	174
		22285_	Semi- detached house		1955	2	Flat	174	3442	20	6127	33625	30262	174
		22285__	Semi- detached house		1955	2	Flat	174	3442	20	6127	33625	30262	174
		15354	Rowhouses		1954	3	Open Gable	432	8904	21	15849	86983	78285	181
		15821	Rowhouses		1954	3	Open Gable	1237	19665	16	35004	192107	172897	140
		15203	Rowhouses		1954	3	Open Gable	416	8784	21	15636	85811	77230	186
		16038	Rowhouses		1954	3	Open Gable	1287	19940	15	35493	194794	175314	136
		15324	Rowhouses		1954	3	Open Gable	429	8248	19	14681	80575	72517	169
		15400	Rowhouses		1954	3	Open Gable	1254	23780	19	42328	232307	209076	167
		22289	Rowhouses		1954	2	Flat	324	6100	19	10858	59591	53632	166
		22289_	Rowhouses		1955	2	Flat	324	6100	19	10858	59591	53632	166
		22290	Rowhouses		1955	2	Flat	324	9296	29	16547	90813	81731	252
		22290_	Rowhouses		1955	2	Flat	324	9296	29	16547	90813	81731	252
		22291	Rowhouses		1955	2	Flat	324	8240	25	14667	80497	72447	224
		22291_	Rowhouses		1955	2	Flat	324	8240	25	14667	80497	72447	224
		15250	Rowhouses		1954	3	Open Gable	416	9376	23	16689	91594	82435	198
		16267	Rowhouses		1954	3	Open Gable	416	7816	19	13912	76355	68719	165
		15232	Rowhouses		1954	3	Open Gable	429	6768	16	12047	66117	59505	139
		15267	Rowhouses		1954	3	Open Gable	416	9944	24	17700	97143	87429	210
		15926	Rowhouses		1954	3	Open Gable	416	7280	18	12958	71118	64006	154
		15252	Rowhouses		1954	3	Open Gable	416	7288	18	12973	71196	64077	154
		22286	Rowhouses		1954	3	Open Gable	378	7720	20	13742	75417	67875	180
		22286_	Rowhouses		1954	2	Flat	324	7720	24	13742	75417	67875	209
		22287	Rowhouses		1954	2	Flat	324	7176	22	12773	70102	63092	195
		22287_	Rowhouses		1954	2	Flat	324	7176	22	12773	70102	63092	195
		22288	Rowhouses		1954	2	Flat	324	6292	19	11200	61467	55320	171
		22288_	Rowhouses		1954	2	Flat	324	6292	19	11200	61467	55320	171
		22288__	Rowhouses		1954	2	Flat	370	6292	17	11200	61467	55320	150
											4995769		24676013	

Area	Neighbourhood	Building block number	House typology	Additional classification	Year of construction	Storeys number	Type of roof	Use surface m2	Gas consumption m3	Gas m3/m2	Gas CO2 emmisions kg	Gas consumption kWh	Heat demand kWh	Heat demand kWh/m2
Slotermeer-Noordoost	Buurt 2	16709	Appartment blocks	Portiekflat		4	flat	2522	36774	15	65457.7	359245.21	323320.69	128
		18940	Appartment blocks	Portiekflat		5	flat	3172	64904	20	115529.1	634047.18	570642.46	180
		19024	Appartment blocks	Portiekflat		5	flat	2784	59643	21	106164.5	582652.47	524387.22	188
		19023	Appartment blocks	Portiekflat		5	flat	2784	60432	22	107569.0	590360.21	531324.19	191
		19064	Appartment blocks	Portiekflat		5	flat	3712	79680	21	141830.4	778393.92	700554.53	189
		18975	Appartment blocks	Portiekflat		4	flat	1418	19888	14	35400.6	194285.87	174857.28	123
		18950	Appartment blocks	Portiekflat		4	flat	1414	17787	13	31660.9	173761.20	156385.08	111
		18103	Appartment blocks	Gallerijflat		9	flat	986	11760	12	20932.8	114883.44	103395.10	105
		18703	Multifamily house			11	flat	4557	46050	10	81969.0	449862.45	404876.21	89
		16750	Multifamily house			11	flat	4579	56661	12	100856.6	553521.31	498169.18	109
		19076	Multifamily house			2&5	sloped	13714	222185	16	395489.3	2170525.27	1953472.74	142
		19021	Appartment blocks	Portiekflat		5	sloped	2491	54544	22	97088.3	532840.34	479556.30	193
		19053	Appartment blocks	Portiekflat		5	sloped	2491	59808	24	106458.2	584264.35	525837.92	211
		18810	Appartment blocks	Portiekflat		4	sloped	2166	32760	15	58312.8	320032.44	288029.20	133
		18807	Appartment blocks	Portiekflat		4	sloped	2082	28796	14	51256.9	281308.12	253177.31	122
		18682	Appartment blocks	Portiekflat		5	flat	3094	54656	18	97287.7	533934.46	480541.02	155
		18683	Appartment blocks	Portiekflat		5	flat	3119	55296	18	98426.9	540186.62	486167.96	156
		18685	Appartment blocks	Portiekflat		5	flat	3118	56784	18	101075.5	554722.90	499250.61	160
		18684	Appartment blocks	Portiekflat		5	flat	3119	57008	18	101474.2	556911.15	501220.04	161
		19075	Multifamily house			2&5	sloped	13188	223488	17	397808.6	2183254.27	1964928.84	149
		19020	Appartment blocks	Portiekflat		5	sloped	2551	50736	20	90310.1	495639.98	446075.99	175
		19018	Appartment blocks	Portiekflat		5	sloped	2519	48160	19	85724.8	470475.04	423427.54	168
											2488084		12289597	

Area	Neighbourhood	Building block number	House typology	Additional classification	Year of construction	Storeys number	Type of roof	Use surface m2	Gas consumption m3	Gas m3/m2	Gas CO2 emmisions kg	Gas consumption kWh	Heat demand kWh	Heat demand kWh/m2
Slotermeer-Zuidwest	Noordoever Sloterplas	16439	Multifamily house		1986	4	flat	15593	218178	14	388357	2131381	1918243	123
		16285	Rowhouses		1986	2	flat	2583	32039	12	57029	312989	281690	109
		16037	Rowhouses		1998	2	flat	1278	16720	13	29762	163338	147004	115
		16143	Rowhouses		1998	2	flat	1268	14938	12	26590	145929	131336	104
		22292	Rowhouses		1998	2	flat	600	10992	18	19566	107381	96643	161
		15452	Rowhouses		1998	2	flat	1291	15092	12	26864	147434	132690	103
		16507	Multifamily house		1998	4	flat	13201	156840	12	279175	1532170	1378953	104
		15471	Appartment blocks	Portiekflat	1955	5	sloped	1218	31160	26	55465	304402	273962	225
		16486	Appartment blocks	Portiekflat	1955	5	sloped	4284	94032	22	167377	918599	826739	193
		15927	Appartment blocks	Portiekflat	1955	5	sloped	1201	27860	23	49591	272164	244948	204
		16545	Appartment blocks	Portiekflat	1955	5	sloped	4212	96624	23	171991	943920	849528	202
		16050	Appartment blocks	Portiekflat	1956	5	sloped	1198	27940	23	49733	272946	245651	205
		16544	Appartment blocks	Portiekflat	1956	5	sloped	4046	89610	22	159506	875400	787860	195
		23498	Apartment blocks	Gallerijflat	1965	15	Flat	12712	51092	4	90944	499118	449206	35
		16468	Apartment blocks	Gallerijflat	1965	15	Flat	12825	16485	1	29343	161042	144938	11
		16495	Apartment blocks	Gallerijflat	1965	15	Flat	12703	49896	4	88815	487434	438691	35
		16457	Multifamily house		1986	5		4625	71262	15	126846	696158	626543	135
		16478	Apartment blocks	Gallerijflat	1957	8	Flat	5934	153052	26	272433	1495165	1345648	227
		15810	Rowhouses			2	Flat	986	23820	24	42400	232698	209428	212
		16650	Appartment blocks	Portiekflat		8	Flat	6000	23296	4	41467	227579	204821	34
											2173252		10734521	

Area	Neighbourhood	Building block number	House typology	Additional classification	Year of construction	Storeys number	Type of roof	Use surface m2	Gas consumption m3	Gas m3/m2	Gas CO2 emmisions kg	Gas consumption kWh	Heat demand kWh	Heat demand kWh/m2
Slotermeer-Zuidwest	Slotermeer Zuid	17948	Multi-family house		1992	6	flat	1225	16443	13	29269	160632	144569	118
		18948	Multi-family house		1998	6	flat	1731	21666	13	38565	211655	190490	110
		18918	Multi-family house		1998	6	flat	1999	22563	11	40162	220418	198376	99
		18920	Multi-family house		1998	6	flat	2007	22333	11	39753	218171	196354	98
		18843	Appartment blocks	Portiekflat	1953	4	sloped	6661	130221	20	231793	1272129	1144916	172
		18781	Rowhouses		1954	2	sloped	1317	32164	24	57252	314210	282789	215
		18782	Rowhouses		1954	2	sloped	1286	21182	16	37704	206927	186234	145
		18780	Rowhouses		1954	2	sloped	1278	21318	17	37946	208256	187430	147
		18747	Rowhouses		1954	2	sloped	1356	23360	17	41581	228204	205383	151
		13179	Rowhouses		1954	2	sloped	1281	35802	28	63728	349750	314775	246
		19371	Rowhouses		1954	2	sloped	1261	29925	24	53267	292337	263104	209
		18358	Rowhouses		1954	2	sloped	483	10836	22	19288	105857	95271	197
		18356	Rowhouses		1954	2	sloped	483	11438	24	20360	111738	100564	208
		18780	Rowhouses		1954	2	sloped	483	10751	22	19137	105027	94524	196
		12819	Rowhouses		1954	2	sloped	552	11360	21	20221	110976	99878	181
		19366	Rowhouses		1954	2	sloped	552	12320	22	21930	120354	108319	196
		16214	Rowhouses		1954	2	sloped	552	12624	23	22471	123324	110991	201
		18148	Rowhouses		1954	2	sloped	552	11472	21	20420	112070	100863	183
		18149	Rowhouses		1954	2	sloped	552	12112	22	21559	118322	106490	193
		18147	Rowhouses		1954	2	sloped	552	14336	26	25518	140048	126044	228
		12819	Rowhouses		1954	2	sloped	552	11920	22	21218	116446	104802	190
		15595	Rowhouses		1954	2	sloped	552	9696	18	17259	94720	85248	154
		15658	Rowhouses		1954	2	sloped	552	10880	20	19366	106287	95658	173
		16387	Rowhouses			2	sloped	1563	39774	25	70798	388552	349697	224
		22295	Detached house (x6)		1956	2	flat	846	17724	21	31549	173146	155831	184
		18073	Rowhouses		1954	2	sloped	410	7310	18	13012	71411	64270	157
		18039	Rowhouses		1954	2	sloped	410	9930	24	17675	97006	87306	213
		18069	Rowhouses		1954	2	sloped	328	6672	20	11876	65179	58661	179
		18105	Rowhouses		1954	2	sloped	328	8680	26	15450	84795	76315	233
		18669	Rowhouses		1954	2	sloped	820	15200	19	27056	148489	133640	163
		18629	Rowhouses		1954	2	sloped	738	15804	21	28131	154389	138950	188
		12971	Rowhouses		1954	2	sloped	656	13072	20	23268	127700	114930	175
		18129	Rowhouses		1954	2	sloped	656	10208	16	18170	99722	89750	137
		18904	Rowhouses		1954	2	sloped	1488	31290	21	55696	305672	275105	185
		18627	Rowhouses		1954	2	sloped	738	14418	20	25664	140849	126764	172
		18592	Rowhouses		1954	2	sloped	738	12996	18	23133	126958	114262	155
		18905	Rowhouses		1954	2	sloped	1483	32095	22	57129	313536	282182	190
		18686	Rowhouses		1954	2	sloped	1419	25330	18	45087	247449	222704	157
		19372	Rowhouses		1954	2	sloped	1402	31790	23	56586	310557	279501	199
		15689	Rowhouses		1953	2	sloped	1472	26964	18	47996	263411	237070	161
		18767	Rowhouses		1957	2	sloped	1157	18368	16	32695	179437	161493	140
		8578	Rowhouses		1957	2	sloped	861	21504	25	38277	210073	189065	220
		13181	Rowhouses		1957	2	sloped	612	11928	19	21232	116525	104872	171
		15858	Rowhouses		1957	2	sloped	612	11435	19	20354	111709	100538	164
		16517	Rowhouses		1954	2	sloped	1519	34891	23	62106	340850	306765	202
		16563	Rowhouses		1954	2	sloped	1483	29592	20	52674	289084	260176	175
		16537	Rowhouses		1954	2	sloped	1511	26530	18	47223	259172	233254	154
		16483	Rowhouses		1954	2	sloped	1559	35036	22	62364	342267	308040	198
		19124	Multifamily house		1953	2	flat	837	18486	22	32905	180590	162531	194
		15820	Multifamily house		1953	2	flat	954	18460	19	32859	180336	162302	170
		15863	Rowhouses		1953	2	sloped	1121	22350	20	39783	218337	196503	175
		15420	Rowhouses		1953	2	sloped	574	15392	27	27398	150364	135328	236
		16274	Rowhouses		1953	2	sloped	618	15105	24	26887	147561	132805	215
		16255	Rowhouses		1953	2	sloped	943	14789	16	26324	144474	130026	138
		15781	Rowhouses		1953	2	sloped	738	19404	26	34539	189558	170602	231
		15525	Rowhouses		1953	2	sloped	1555	28440	18	50623	277830	250047	161
		3390	Rowhouses		1953	2	sloped	1564	31692	20	56412	309599	278639	178
		16091	Rowhouses		1953	2	sloped	1125	17790	16	31666	173791	156411	139
		15765	Rowhouses		1953	2	sloped	1065	16192	15	28822	158180	142362	134
		19116	Rowhouses		1953	2	sloped	2258	44484	20	79182	434564	391108	173
		15395	Rowhouses		1953	2	sloped	1110	25648	23	45653	250555	225500	203
		15594	Rowhouses		1953	2	sloped	541	11976	22	21317	116994	105294	195
		15654	Rowhouses		1953	2	sloped	541	11440	21	20363	111757	100582	186
		15993	Rowhouses		1953	2	sloped	541	12280	23	21858	119963	107967	200
		15415	Rowhouses		1953	2	sloped	541	9919	18	17656	96899	87209	161
		15533	Rowhouses		1953	2	sloped	541	11912	22	21203	116368	104731	194
		15205	Rowhouses		1953	2	sloped	541	13496	25	24023	131842	118658	219
		16428	Appartment blocks	Portiekflat	1954	5	flat	4667	77328	17	137644	755417	679876	146
		16640	Appartment blocks	Portiekflat	1953	5	flat	4685	82008	18	145974	801136	721023	154
		16212	Appartment blocks	Gallerijflat	1958	5	flat	2471	62744	25	111684	612946	551652	223
		16640	Appartment blocks	Gallerijflat	1958	8	flat	5639	20826	4	37070	203449	183104	32
		16677	Appartment blocks	Portiekflat	1953	3	sloped	972	16920	17	30118	165291	148762	153
		15603	Appartment blocks	Portiekflat	1953	3	sloped	972	19170	20	34123	187272	168545	173
		15838	Appartment blocks	Portiekflat	1953	3	sloped	972	21600	22	38448	211010	189909	195
		15882	Appartment blocks	Portiekflat	1953	3	sloped	972	19674	20	35020	192195	172976	178
		15994	Appartment blocks	Portiekflat	1953	3	sloped	972	19728	20	35116	192723	173451	178
		15836	Appartment blocks	Portiekflat	1953	3	sloped	972	20340	21	36205	198701	178831	184
		15979	Rowhouses		1958	2	flat	1030	23420	23	41688	228790	205911	200
		16295				7	flat	5906	29532	5	52567	288498	259648	44
											3231647		15962339	