Roadmap to nearly Zero Energy Buildings

Towards nZEBs in 2020 in the Netherlands

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Preface

This study was commissioned by Royal HaskoningDHV (RHDHV) and TVVL in cooperation with the Eindhoven University of Technology (TU/e). The study was conducted as an internship project for the master Sustainable Energy Technology at TU/e. The aim of this study was to prepare a roadmap for nZEBs (nearly Zero Energy Buildings) towards 2020 in the Netherlands.

The aim of this report is to provide insight on nZEB solutions for the Dutch situation. First the European definition of an nZEB is given and examples of nZEBs in the Netherlands. Next the potential of nZEBs will be investigated by determining status and policies on Dutch energy infrastructure and current and innovative energy saving measures. Scenarios for three different areas will be determined for reference buildings to which innovative building techniques are applied. Finally a cost-optimality calculation is performed to determine whether the scenarios are financially feasible. A full description of the internship assignment description can be found in Appendix I.

The report has been written for RHDHV (Wim Maassen), TVVL (Hans Besselink) to support their research towards nZEB and as internship project for the TU/e (Wim Zeiler). The AASA group, including Jarek Kurnitski (Tallinn University of Technology/REHVA), Jan Aerts (ISSO Netherlands) and Jeroen Rietkerk (TVVL), was also involved and has supported the nZEB project. The content of this report has to be treated confidential.

Rotterdam, April 2014

Summary

This report describes a roadmap towards nZEB in the Netherlands. The main focus of this study is to map current nZEB status and provide a cost optimality calculation for nZEB scenarios. The technical and financially feasibility show that nZEBs have good potential in the Netherlands.

The first chapter starts with the definition of nZEBs according to the framework of the European Commission: the EPBD (Energy Performance of Buildings Directive). The directive states that nZEBs should have and energy consumption close to 0 kWh/(m^2a) achieved with a combination energy efficiency measures and renewable energy technologies. Important features are discussed such as on-site and off-site energy production, which requires appropriate legislation to stimulate renewable energy sources.

The second chapter describes the current situation on building performance requirements for newly built and existing buildings. The situation in the Netherlands and Europe is discussed to get a good overview on the overall nZEB status. Currently the Dutch government has not yet proposed an nZEB definition. In order to create an energy neutral building stock in the Netherlands, renovation rate and depth should be increased significantly.
Examples of nZEBs in the Netherlands show already existing buildings which technically satisfy future regulation. In order to provide insight to energy saving measures and installations, comparisons are made for three building categories: single family house, apartment blocks and office buildings.

The nZEB potential in the Netherlands is described in chapter three. The energy infrastructure is discussed and example projects of smart grids applying different techniques are shown. Furthermore an overview of energy saving measures, interesting for nZEBs, is shown; the overview is presented according to an adapted Trias Energetica approach. Two systems show the best potential in the Netherlands: the GSHP (Ground Source Heat Pump) and ATES (Aquifer Thermal Energy Storage) systems. Furthermore mechanical ventilation with heat recovery and large scale PV application are recommended.

In chapter four nZEB scenarios are determined for three areas: Urban area, Suburban area, and Rural area. For every area a reference building according to coming regulation is determined, using existing techniques (construction and installation). Three nZEB scenarios are composed using energy saving measures currently being developed, to reduce energy consumption and proved sustainable (on-site) energy production. EPC scores and primary energy values are determined with the ENROM tool.
For all three areas a view is given on the current and future energy infrastructure. Smart grids, energy exchange between buildings on a local level, will play an important role in future energy infrastructure.

Chapter five describes the cost optimality calculation performed for a middle sized office building. LCC calculation methods are used to determine all building cost over a life span of 30 years. Additional gains such as increased productivity and reduced sick leave are incorporated in the LCC’ calculation, resulting in positive economic feasibility of the three nZEB scenarios. An average EPC score of 0.2 (≈ 20 kWh/(m^2a)) was accomplished for the three nZEB scenarios. The scenarios incorporating GSHP and ATES systems show best potential. The cost optimality includes financial and macro-economic analyses, followed by a sensitivity analysis.

Abbreviations

ACH	Air Change per Hour
AIDA	Affirmative Integrated energy Design Action
ATES	Aquifer Thermal Energy Storage
BPIE	Buildings Performance Institute Europe
CA EPBD	Concerted Action EPBD
CAPEX	Capital Expenses
CCA	Concrete Core Activation
CHP	Combined Heat and Power
DUBO	Duurzaam Bouwen (Sustainable Construction)
ECN	Energieonderzoek Centrum Nederland
EMG	Energieprestatienorm voor Maatregelen op Gebiedsniveau
EU	European Union
EURIMA	European Insulation Manufacturers Association
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Coefficient
EV	Electric Vehicle
EWA	European Windtunnel Association
EWEA	European Wind Energy Association
GGP	Green Gas Project
GSHP	Ground Source Heat Pump
LCC	Life Cycle Cost
LCC’	Life Cycle Cost with additional gains
LTES	Long Term Energy Storage
MGT	Micro Gas Turbine
MS	Member State
NPV	Net Present Value
NPEC	Net Present Extra Cost
nZEB	nearly Zero Energy Building
OPEX	Operational Expenses
PBP	PayBack Period
PCM	Phase Changing Material
PMC	Power Matching City
PV	Photo Voltaic
PVT	Photo Voltaic Thermal
RCI	Rotterdam Climate Initiative
REHVA	Federation of European Heating, Ventilation and Air-conditioning Associations
REAP	Rotterdam Energy Approach and Planning
RHDHV	Royal HaskoningDHV
SC	Solar Collector
SDE	Stichting Duurzame Energieproductie
SOFC	Solid Oxide Fuel Cell
UKP NESK	Unique Opportunity Program to Energy Neutral Schools and Offices
VIP	Vacuum Insulation Panels
WFS	Woven Fabric Subwaste
WFW	Woven Fabric Waste

Content

Introduction

The aim of this report is to provide information and insight on nZEB developments that will occur in the near future and what consequences of these developments have for buildings, in particular for building services. This project is realized by a co-operation between RHDHV and TVVL, in collaboration with the TU/e.

In 2010 the European Commission has launched the Energy Performance on Building Directive (EPBD) with the main targets to reduce CO_2 emissions with 90% compared to 1990. The EPBD requires all newly build buildings to be nZEB in 2020 for different building functions. Existing buildings will also have to comply with this regulation towards 2050. Each European Member State (MS) has to work out a plan that includes an nZEB definition for different building functions, determining specific building requirements.

The Dutch government has set out a plan to implement nZEB regulation for the coming years. In the nearby future (2015/2017), the Energy Performance Coefficient (EPC) demand will be lowered for residential buildings and non-residential buildings. In 2020 all newly build buildings have to comply with the nZEB regulation (EPC ≈ 0).

To support the future policy on energy performance improvements, this study will provide a roadmap towards nZEBs with a technical and financial feasibility study. Cost-optimality calculations are essential for determining the Dutch nZEB definition, because they determine if the energy efficient measures are cost effective and can be implemented in the building law. In the near future EPC requirements will be reduced to values that lay within the so-called ’’Cost optimal range’’ as shown in Figure 1 (green area). This range is determined by calculating the Life Cycle Costs (LCCs) over a period of 30 years.
In 2020 buildings will have to be nZEBs (blue area in Figure 1). The nZEB level is determined by each EU MS based on the economic feasibility. Current calculations show that nZEBs will result in much higher LCC values than the economic optimum. Therefore a LCC method which also takes additional gains (e.g. productivity, resale value) into account will be proposed to reduce costs and shift the economic optimum towards nZEB requirements (blue arrow in Figure 1). This calculation method serves as an important foundation for the Roadmap towards nZEBs.

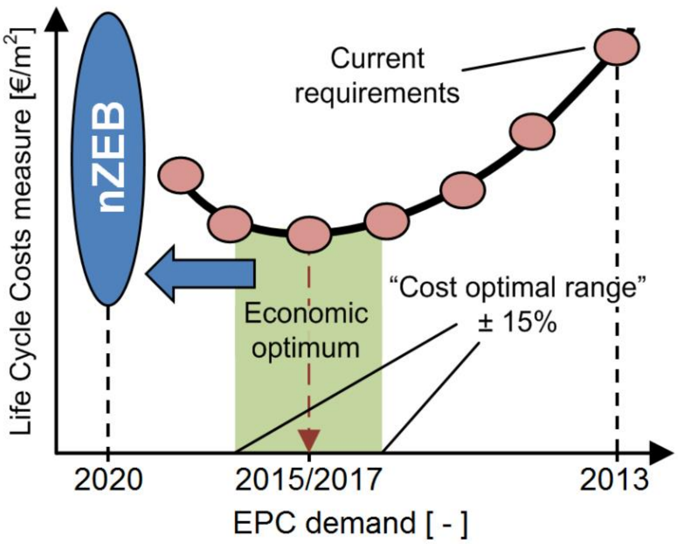


Figure 1: Lice Cycle Costs versus the EPC-demand.

Background

In Europe, around 40% of the existing building stock was constructed before the 1960s when building energy codes were almost none existing. When oil prices increased in the 1970s, several EU MS introduced requirements for the thermal performance in their building codes, with the exception of some Scandinavian countries which already had requirements in place. New residential buildings in Europe are estimated to consume about 60% less energy on average than those buildings constructed before the mid-1970s. [1] With sharply increasing energy prices in the 21st century, regulations concerning energy performance for newly built and renovated buildings are of crucial importance.

On 19th May 2010, a recast of the EPBD was adopted by European commission to launch their target towards nZEB in 2020. EU MS need to determine an exact definition of an nZEB using the EPBD recast.
Following the EPBD recast, the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) realized a report [2] with intention to help the experts in the MS to define the nZEBs in a uniform way. Technical definitions and related specifications are prepared in the level of detail to be suitable for the implementation in national building codes. This literature will be used in defining the requirements and regulations for reference buildings.

Table 1: EPC demand for residential buildings in the Netherlands.

Date of application	EPC
1 January 1996	1.4
1 January 1998	1.2
1 January 2000	1.0
1 January 2006	0.8
1 January 2011	0.6
1 January 2015	0.4

The Dutch government has published the 'National Plan to promote nZEBs' [3] in September 2012 following the EPBD recast by indicating the understanding of a "nearly Zero Energy Building". In the Netherlands performance is indicated by the Energy Performance Coefficient (EPC) which is described in the NEN 7120 norm. Currently, the EPC is 0.6 for residential buildings and according to the 'Lente Akkoord' (2008) EPC will be lowered to 0.4 in 2015. The Lente Akkoord is a covenant of the new buildings sector, aimed at reducing the energy consumption of new buildings over time. In this signed agreement between the public and private sectors, a number of efforts have been agreed to reduce the energy use of new buildings by the year 2015 by at least 50% compared to 2007 levels. [3]
The 'National Plan for promoting nZEBs' describes governmental activities to stimulate the development of nZEBs by [4];

- Setting clear goals for all stakeholders and the establishment of clear laws and regulations; defining the EPC value for residential and non-residential buildings.
- Acquiring a broad support among all stakeholders, including residents and users.
- Appreciating collective solutions.
- Encouraging sufficient knowledge to all players.
- Stimulating cooperation in the chain, (i.e. optimizing performance of the construction sector through continuous improvement: cooperation of chain partners and stakeholders in the building process).
- To provide room for experimentation; for example the program 'Excellente Gebieden' were upcoming EPC requirements are tested for 19 innovative project spread across the country.
- Acting as a launching customer: the government will be the first big customer of an innovative product.

1 Definition

In this chapter the definition of the nZEB is given according to the EPBD recast. Furthermore a brief description of requirements is given to which future regulation and implementation of an nZEB should apply to. A vision on the nZEB definition for the Dutch situation will be discussed at the end.

1.1 What is an nZEB?

The definition on a "nearly Zero Energy Building" is described within the EPBD recast of the EU [5] and it is specified that by 31st December 2020 all new buildings shall be "nearly zero energy buildings". Governmental buildings occupied and owned by public authorities, will have to be "nearly zero energy buildings" by 31st December 2018 according to the EPBD recast. The actual definition of nZEB is given in Article 9 of the EPBD:

> *"Nearly Zero Energy Building (nZEB): Technical and reasonably achievable national energy use of > 0 kWh/(m²a) but no more than a national limit value of non-renewable primary energy, achieved with a combination of best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal."* [2]

Note 1: 'reasonable achievable' means by comparison with national energy use benchmarks appropriate to the activities served by the building, or any other metric that is deemed appropriate by each EU MS.
Note 2: The European Commission has established a comparative methodology framework for calculation of cost-optimal levels (Cost-Optimal). [6]
Note 3: Renewable energy technologies needed in nZEBs may or may not be cost-effective, depending on available national financial incentives.

1.2 Requirements and regulations for nZEBs

The EPBD describes requirements to which nZEBs should comply with. MS will have to apply methodology for calculating energy performance of buildings in according to Annex I in the EPBD [5]. This methodology has been adopted for the Dutch situation in which the referential buildings have been categorized:

a) single family houses of different types;
b) apartment block and multifamily houses;
c) office buildings.

Other referential buildings in the non-residential building category (mentioned in Appendix I of the EPBD) for which specific energy performance requirements exist are:

d) educational buildings;
e) hospitals;
f) hotels and restaurants;
g) sports facilities;
h) wholesale and retail trade services buildings;
i) other types of energy-consuming buildings.

The common general framework (from EPBD) describes that energy performance has to be determined on the basis of the calculated or actual energy that is consumed and has to reflect the heating and cooling energy needs to maintain the envisaged temperature conditions of the building, and domestic hot water needs. The energy performance has to be expressed in a transparent manner and shall include an energy performance indicator and a numeric indicator of primary energy use, which may be based on national or regional annual weighted averages or a specific value for on-site production. [5]

The methodology has to take into consideration (at least) the following aspects [5]:

a) *thermal characteristics* of the building: thermal capacity, insulation, passive heating, cooling elements, and thermal bridges;
b) *heating installation* and *hot water supply*, including their insulation characteristics;
c) *air-conditioning installations*;
d) *natural and mechanical ventilation* which may include air-tightness;
e) built-in *lighting installation* (mainly in the non-residential sector);
f) the *design, positioning and orientation of the building*, including outdoor climate;
g) *passive solar systems* and *solar protection*;
h) *indoor climatic conditions*, including the designed indoor climate;
i) *internal loads*.

The positive influence of external influences shall, where relevant, be taken into account [5]:

a) local *solar exposure* conditions, active solar systems and other heating and electricity systems based on energy from renewable sources;
b) electricity produced by *cogeneration*;
c) *district or block heating and cooling systems*;
d) *natural lighting*.

The National Plan to promote nZEBs [3] promotes usage of renewable energy source for nZEBs; it enhances the definition from the Renewable Energy Directive (2009/28/EC) [7]. According to the EPG (Energie Prestatie voor Gebiedsniveau) the 'Trias Energetica' approach may be applied by the building parties. The Trias Energetica stepped approach is as follows:

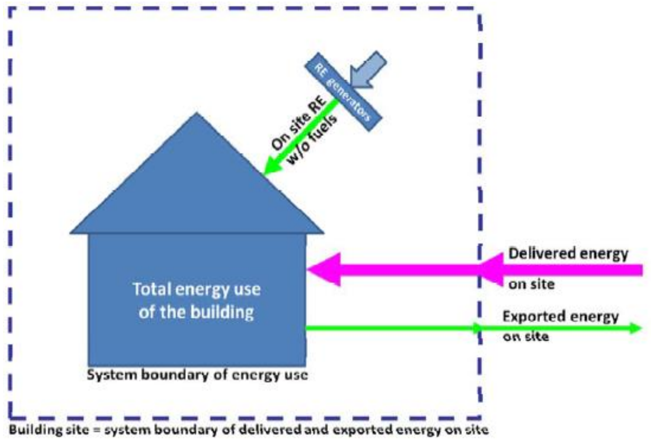
1. reduce the demand for (primary) energy;
2. apply renewable energy sources;
3. use fossil fuels efficiently.

The aim is to increase the share of renewable energy by decreasing the EPC towards nZEBs. Also the boundary conditions concerning the thermal insulation of the building envelope and U-values for windows are tightened to reduce energy losses. The current status and future measures concerning the EPC in the Netherlands is described in chapter 2.1.1.

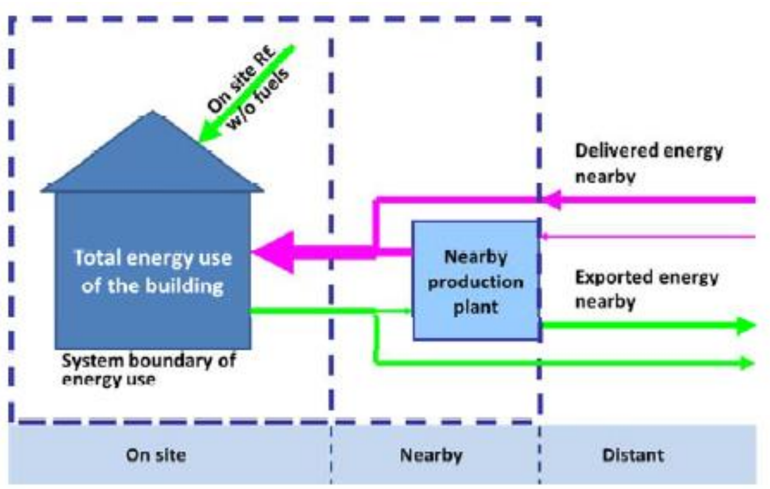
In the REHVA nZEB Report 2013 [2] technical definitions (according to prNEN 15603:2013) regarding boundaries of the building site and nearby/distant energy production is given. Basic energy balances of delivered and exported energy system boundaries for the primary and renewable energy are given, shown in Figure 2. The system boundary definitions apply for a single building or for sites with multiple buildings with or without nearby production.

Definitions of system boundaries for energy use are:

- *Energy use system boundary*: (also 'building boundary') includes all areas associated with the building (both inside and outside) where energy is used or produced, but excludes the building technical systems converting on-site renewable energy source (normally placed at partially outside the building envelope)
- *Building site boundary*: the extension of the building boundary which includes the technical systems converting on-site renewable energy sources.
- *Nearby boundary*: the extension which has to be defined on national bases to include nearby renewable energy production that is contractually linked to the building.



System boundaries for on-site assessment (nearby production not linked to the building) for nZEB definition, connecting a building to energy networks and using on-site renewable energy sources. System boundary of energy use of building technical systems follows outer surface of the building in this simplified figure; system boundary of delivered and exported energy on site is shown with dashed line.



Nearby assessment boundary to be used in the case of nearby energy production linked contractually to the building. Compared to on-site assessment boundary, delivered and exported energy flows on-site are replaced by delivered and exported energy flows nearby.

Figure 2: System boundaries for nZEBs for a) on-site energy production and b) nearby energy production. [2]

The definition of nearby energy production will be important to buildings in urban areas since dense building constructions create enormous challenges for on-site renewable energy production. In order to be able to take into account a new nearby renewable energy production capacity contractually linked to a building (site), it is a prerequisite to have fitting national legislation. This legislation should allow allocating new capacity to the building/development with a long term contract and assuring that investment on that new capacity will lead to a real addition to the grid or district heating or cooling mix. [2]

1.3 Vision

This section describes a vision about nZEB definition for the Dutch situation.

The framework for nZEB specification has been provided by the European Commission; the next step for the Dutch government is to determine an nZEB definition for all building functions mentioned in the Bouwbesluit. Current plans and ideas have been presented and are further discussed in chapter 2.1.1.

The goal of nZEB is to reduce energy consumption and the related emissions. Fossil fuels, such as gas and coal, powering electricity plants and providing heating, are getting depleted causing energy prices to increase. When reducing energy consumptions of the built environment, EU countries become less dependent on energy from unstable regions, something that is desirable considering increasing instability in these countries.

The EU nZEB definition states that nZEBs should be provided with renewable energy sources. Building density in the Netherlands is high; especially in the Randstad were almost half of the Dutch population lives. This fact is important for sustainable energy production, since most renewable energy techniques have low energy production capacity per land area (surface) compared to a conventional power plant. Also the low efficiency makes them unattractive. These facts make it difficult to provide sustainable energy to buildings in densely populated areas.
According to the EPBD nearby (off-site) sustainable energy production sites will have to be contractually linked to a building (site). To accommodate this type of energy production, fitting legislation will have to be in place. Without the proper regulation it would be quite convenient to contractually link an energy inefficient building to green energy production sites, to become an nZEB. However, this goes against the idea of nZEBs which should provide its renewable energy on-site.
The principle of Trias Energetica could be guidance for the nZEB definition. Three steps are involved with Trias Energetica:

1. reduce energy consumption;
2. use renewable energy sources;
3. use non-renewable energy sources as efficiently as possible.

The second and the third standard should be replaced by:

2. use on-site renewable energy sources;
3. use off-site renewable energy sources as little as possible.

To stimulate on-site production and minimize building designs that are sustainable ‘on paper’, legislation should prescribe that building have to utilize maximum amount of sustainable on-site renewable energy, before contractually link the building to off-site energy production. It is however difficult to determine whether a builder/constructor has considered a wide variance of sustainable energy measures.
It is therefore advised to consider a legislative system determining on-site sustainable energy yield dependent on the building density. For example, a certain percentage of energy may be contractually imported when a building is built in a dense area.

2 Current situation

The current situation regarding nZEBs is discussed in this chapter. First there will be a discussion about the status on nZEBs in the Netherlands and the rest of Europe. Second there will be examples and comparisons of nZEB in the Netherlands for three building types: a family home, an apartment block and an office building.

2.1 Status on nZEBs

In this section ideas about nZEBs in the Netherlands and Europe are discussed. Building performance in the Netherlands is expressed in Energy Performance Coefficient (EPC). Current and future status on EPC demands is discussed and the effect of changing the EPC is evaluated. The current status and progress of implementation of the EPBD directive in Europe is analysed by comparing different information sources; discussing building energy requirements, legislative framework and financial schemes.

2.1.1 The Netherlands

Dutch energy performance certificates have been in place since the beginning of 2008. To determine the EPC, levels of insulation (roof/walls/floor and window including frame) and installations (heating, cooling, hot water, ventilation, and lighting) are taken into account.
The EPC is a policy tool (according to NEN 7120) providing a calculation method for building energy performance. The EPC gives an indication of the primary energy demand; however the actual demand is mainly dependent by occupant behaviour. Therefore a difference should be made between EPC scores and actually measured energy consumption of buildings.
During the period from 2008 until the end of 2012 over 2.4 million residential energy performance certificates were issued, covering more than 30% of the residential building stock. In the non-residential sector, a total of 15,000 certificates were issued in the same period, mainly for offices, retail and shops or shopping malls. [8] Figure 3 shows cumulative numbers of energy performance certificates for the residential sector in the Netherlands.

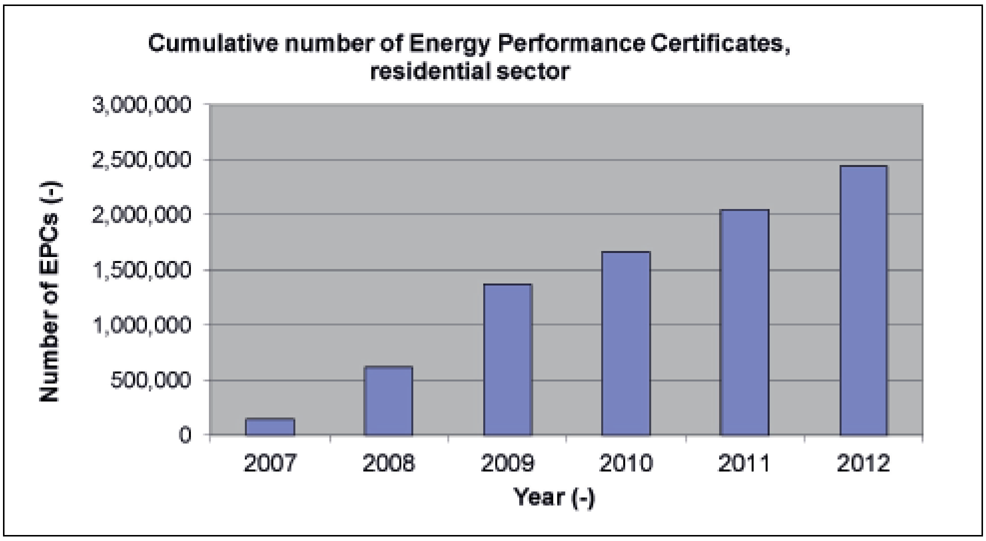


Figure 3: Growth of number of residential EPCs in the Netherlands. [8]

In current Dutch building legislation new requirements are set for the energy efficiency of new buildings and major renovations of existing buildings (25% of building costs). The Netherlands has currently (November 2013) not applied any mandatory requirements for

energy renovation of buildings, but has instead put more focus on a series of support programmes and collaboration initiatives that facilitate building energy retrofits. The Energy Efficiency Directive [9] requires EU Member State to establish by April 2014 a long-term strategy to mobilise investment in the renovation of national building stocks. A summary of renovation related requirements in European directives is provided in Table 2. [10]
Further discussion on future renovation requirements and projected pathways to satisfy the future EU targets can be found in chapter 2.1.3.

Table 2: Overview of renovation related provisions of European Directives. [10]

Provisions of renovation requirements in European Directives	
Energy Performance of Buildings Directive (EPBD, 2002/91/EC) [5]	Article 7: When buildings undergo major renovation, the energy performance of the building or the renovated part thereof needs to be upgraded in order to meet minimum energy performance requirements in so far as this is technically, functionally and economically feasible.
	'*major renovation*' means the renovation of a building where: a) the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25 % of the value of the building, excluding the value of the land upon which the building is situated; or b) more than 25 % of the surface of the building envelope undergoes renovation;
Energy Efficiency Directive (EED 2012/27/EU) [9]	Article 4: Member States shall establish a long-term strategy for mobilizing investment in the renovation of the national stock of residential and commercial buildings, both public and private.
	Article 5: Obligation for a renovation quota of 3% of all public buildings owned and occupied by central governments.
Renewable Energy Directive (2009/28/EC) [7]	Member States should introduce measures to increase the share of energy from renewable sources in new and renovated buildings

Table 3 shows an overview of EPC requirements for Dutch buildings for both the residential and non-residential sector. Over the years, the EPC demand for residential buildings has been tightened from 1.4 at the start in 1995, to 0.6 from January 2011 onwards. Building companies have agreed with the Dutch government on a further tightening of the requirements in the near future, in order to move towards nZEB in 2018 (governmental buildings) and 2020 (all other buildings). The EPC requirement for the residential sector is scheduled to decrease to 0.4 in 2015. For the non-residential sector, this requirement is scheduled to be lessened by 50% by 2017 compared to the EPC requirements of 2007. [8]

Table 3: Current and future EPC requirements for Dutch buildings. [3][8][9]

	EPC-demands			
	Current policy	Future policy		
		2015	2017 (1)(2)	2020
Residential buildings	0.6	0.4 (1)		≈ 0 (1) all buildings *"nearly Zero Energy Buildings"* Governmental buildings have to be nZEB in 2018
Offices	1.1		0.8 (1)	
Health, clinical	2.6		1.8 (1)	
Health, non-clinical	1.0		0.9 (1)	
Educational	1.3		0.7 (1)	
Retail	2.6		1.7 (1)	
Sports	1.8		0.9 (1)	

(1) According to the National Plan to promote nearly Zero Energy Buildings in the Netherlands
*(2) 50% decrease*d primary energy consumption compared to 2007 for governmental buildings

In addition to the EPC requirements, minimum requirements for building components are in place and are shown in Table 4. These requirements apply to new buildings as well as major renovations of existing buildings. Every couple of years, building component requirements are evaluated in terms of cost effectiveness, among other aspects, and (if possible) the requirements are tightened. The Dutch policy for new buildings already incorporates most of the requirements resulting from the EPBD recast towards nZEB in 2020. Requirements for existing buildings are still under discussion and will become mandatory in the course of 2014. [8]

Table 4: R_c and U-values requirements for residential, non-residential, and government buildings. [8]

	R_c [m^2K/W] for all building envelop parts	U-value [W/m^2K] for windows including framework
At present	3.5	1.65
2015	5.0*	-

*scheduled to take place in 2015

According to the CA EPBD report [8] communication is the keyword in future projects relating to the implementation of the EPBD in the near future with the aim of actually stimulating building owners to take energy saving measures following the certification of a building, or the inspections of an installation. Main concerns in the residential sector will be to ensure that home-owners expenditures remain affordable. In the non-residential sector and in the social housing sector, the EPC is considered a useful benchmarking tool where one can distinguish oneself from competitors with an energy efficient building stock.

In the Netherlands energy labels (energy performance certificates) for newly built residential buildings were introduced in 2008 already. The label is designed to indicate energy performance of a building showing the R-values of building envelope components and U-value of glass. [11] Governmental buildings already have to show energy labels in public buildings which have to be clearly visible for the public.

For residential buildings, the label will be adapted in the course of 2013 according to new legislation with additional labels A+++ and A++++. Figure 4 and Figure 5 show the proposed energy label classes and corresponding EPC values for residential buildings. [12]

Figure 4: Energy label classes. [12]

Table 5: Energy labels and corresponding EPC for residential buildings. [12]

Label	Energy Performance Coefficient
A++++	EPC ≤ 0.20
A++	0.40 < EPC ≤ 0.60
A+++	0.20 < EPC ≤ 0.40
A+	0.60 < EPC ≤ 0.80
A	0.80 < EPC ≤ 1.05

Currently the EMG (Energieprestatienorm voor Maatregelen op Gebiedsniveau, translated as Energy Performance Measures at Area Level) is applied for collectively generating heat, cold or electricity. The area in which the EMG may be applied is described in the EMG. For heat, cold and hot tap water there has to be a physical connection between the building and the generator. For electricity generation a maximal distance of 10km may be present between a collective electricity generation plant and a parcel. In addition there should also be a coherent

development of the area and energy infrastructures. The EMG is adopted since July 2012, which means that not much experience has been obtained yet. [3]
In the National Plan to promote nZEBs of September 2012 it is mentioned that there is still insufficient knowledge about innovative techniques and concepts that are suitable to realize an EPC close to zero in 2018/2020. Main concerns are weather the techniques are ready for the market and if they comply with boundary conditions for a healthy indoor climate and cost effectiveness. An important feature for determining demands of the EPC is that building parties can determine their selves which measures have to be taken to comply with the regulations. [3]

Seen many parties are involved with the new legislation, in 2010 ECN (Energy research Centre of the Netherlands) performed a survey [13] on tightening EPC demands. Major building parties were interviewed about the tightening of the EPC from 1.0 to 0.8 in 2006, and also future plans to reduce the EPC further towards 0.6 in 2011 and 0.4 in 2015. The interviewed building parties consisted of:

- Project developers; selected on advice of industry association NEPROM.
- Building corporations; selected on basis of building production.
- A selection of advisors from smaller and larger bureaus.
- Building firms; selected of a members list of Bouwend Nederland; mainly large firms who work in the project-based housing development.
- Municipal supervisors; selected on basis of construction output and national coverage.
- Installers; selected from the membership list of the group Project-based Sanitary Installations UNETO / VNI.

Many building parties are aiming for new energy efficient buildings and evaluate the tightening EPC-demands as positive; however they are critical towards further reducing the EPC towards 0.6 and 0.4 because doubts about the energy saving effects (from EPC = 1.0 to 0.8). Preconditions advised by the parties are that new regulations may not compromise the health and thermal comfort of building users. Market players foresee risks when tightening the EPC leads to, increased number of/and complex installations which have higher maintenance costs, and appliance of new immature (innovative) techniques. They are also critical about the cost-effectiveness of increasing R-values and decreasing U-values because of reduced financial outcome. Building developers say that it is difficult to take into account costs of the energy reducing measures in the renting or sales prices of houses. Building companies also warn for the ‘rebound effect’ resulting in more use of energy after implementation of energy efficient measures. [13]

2.1.2 Europe

The status on nZEBs in Europe is discussed to determine the progress in of implementation of the EPBD directive and the nZEB definition. Different information sources have been consulted to get a broad perspective to map the current situation.

Figure 5 shows the number of energy performance certificates issued in various European countries during the period 2009 till 2012 [14]. From this figure can be concluded that there is quite difference to which extent implementation of energy certificates is conducted. With almost 2.5 million certificates, the Netherlands is one of the leading countries in Europe.

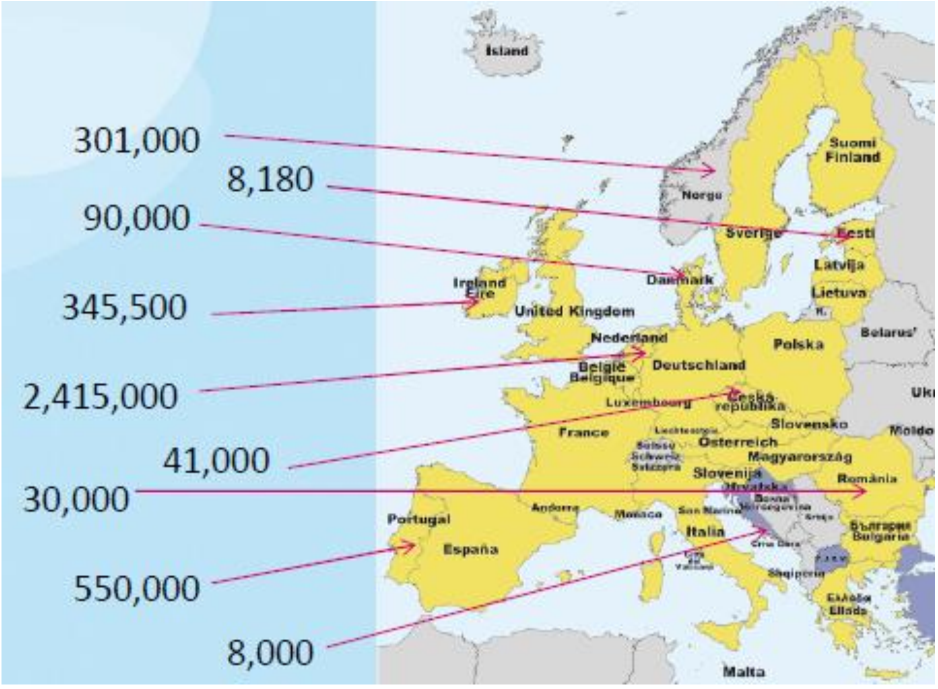


Figure 5: Number of Energy Performance Certificates issued during 2009-2012. [14]

The SustainCo project is a consortium of European energy agencies from Austria, Ireland, UK, Romania and Croatia, which aims to support ambitious European vision for the energy performance of its buildings. In September 2012 SustainCo prepared a report [15] with an overview of EU and national legislation (of SustainCo project partners) regarding energy performance in building sector and funding sources available for implementation of nZEB or similar building standards.
From this report could be concluded that only Spain had not yet started the process of transformation of the national legislative framework for adoption of nZEB standard. The best progress in adoption of nZEB standard has been made in Austria, with adoption of OIB guideline; legislation already adopted in the respective building laws, making it legally binding. Most countries, (Croatia, Ireland, Romania and UK) have implemented 20/20/20 target in their National action plans according to the EPBD Directive 2006/32/EC and have started working on implementing EPBD Directive 2010/32/EC requirements. In Norway an action plan for energy efficiency is planned to be introduced by the government, with the aim of reducing overall energy use in the building sector considerably by 2020. Energy use requirements in the building regulations will be tightened to passive house standard in 2015 and to close to zero-energy standard by 2020. [15]
Most of the countries participating in the SustainCo project have financial schemes already in place in which finance renewable energy and efficiency energy projects for the public and private sector are supported. Austria has developed support schemes for residential and non-residential buildings funding. Most of the countries have feed-in tariffs in place giving subsidies through national institutional funds for implementing renewable energy source measures in private households. All countries participating in SustainCo project have financial framework ready to adopt new funding sources, like Structural and Cohesion funds regarding support to nZEB projects in national or regional level. [15]

Enforcing energy-related requirements are important to achieve the goals set out in the EPBD directive. In the paper by M. Economidou [1] (March 2012) performance base requirements for new buildings and requirements on heating, ventilation and air-conditioning systems are discussed for all EU countries.

Economidou created a table with detailed energy performance requirements for new buildings. This table shows many different approaches; there are not two countries who have adopted the same approach. A variety of calculation methods are used and major differences exist in definitions (e.g. definitions of primary and final energy, heated floor area, carbon conversion factors, regulated energy and total energy requirement). [1]
The setting of building code requirements in most cases based on an absolute value (20 countries), generally expressed in kWh/m²a or on a percentage improvement requirement based on a reference building of the same type, size, shape and orientation. In the Netherlands the EPC is used, as discussed in previous section. Some countries (Belgium) express the performance requirement as having to meet a defined “E value” on a 0 to 100 scale, or on an A+ to G scale (Italy and Cyprus). It should be noted that in many countries the requirements extend only to certain building types, usually just covering the residential sector, no governmental buildings. [1]
Economidou alerts that, as the energy performance requirements (in line with EPBD recast) become stricter, the gap between the theoretical performance during design phase and the actual energy performance in-use may increase substantially. She states that if the EU MS are to deliver the climate and environmental targets related to buildings in the coming years, it is critical that they focus and invest more on control and enforcement procedures. [1]

The report of the Concerted Action Energy Performance of Buildings Directive (CA EPBD) features Country Reports from 2012 [8] on the nZEB status of EU MS. National applications of the nZEB definition have been gathered and compared. From a total of 19 countries that provided detailed information in March 2013 the situation is the following [8]:

- 6 countries have their nZEB application fixed in a legal document;
- 6 countries have the application ready but not yet legally fixed;
- 7 countries are at various stages of developing the application of the NZEB definition, with national studies already performed and currently being evaluated, or with studies still being underway.

The analysis of national nZEB applications also focused on the integration of renewable energy systems. 18 MS answered questions about renewable energy generation systems that will be included in their studies of (innovative) techniques for nZEBs:

- Solar thermal (solar collector): 18 MS.
- Photovoltaic (PV cells): 17 MS.
- Passive solar, day-lighting, biomass: 16 MS.
- Heat recovery, passive cooling and geothermal: 15 MS.
- Biogas: 14 MS.
- Micro wind generator, micro Combined Heat Power (CHP), ambient air (in air-to-air heat pumps) and bio fuel: 13 MS.
- Waste heat (from industries, computer server rooms) and solar cooling: 9 MS.
- Waste heat from hot water (bath/shower, washing machines): 6 MS.

For some of these energy saving techniques, it remains difficult to express renewable energy contributions in the energy performance certificate; for example day-lighting systems and heat recovery.

A difficult issue exist between the nZEB definition and the cost-optimal energy performance requirements. Several major parameters cannot be easily predicted for the coming years, such as future performance of new and further developed technologies, future primary energy factors (electricity, or district heating), due to changes in infrastructure, cost developments of technologies, energy carriers, labour and planning, as well as boundaries like changing climate and lifestyle. [8]

AIDA (Affirmative Integrated energy Design Action) is a consortium of institutes, universities and research centres from 8 EU countries whose aims are to increase the number of nZEBs, the number of building professionals trained on 'integrated energy design' and the number of municipalities starting to build/refurbish buildings to nZEB levels. In one of their reports they describe how to integrate the energy performance requirements in the public design tenders, with proposed minimum energy performance indexes for nZEBs [16]:

- The highest class (usually standard Class A) of the National or Local Energy Performance Classification of the building;
- The 50-70% of the primary energy consumption has to be covered by energy produced from renewable energy sources;
- Total primary energy consumption limit: 50-60 kWh/m^2year;
- CO_2 emission limit: 3-8 kg CO_2/m^2year.

These performance indexes give a view on how the definition for the Dutch situation might look like.

2.1.3 Renovation of existing buildings

This paragraph describes the current goals of the EU concerning renovation of existing buildings. Furthermore two examples of renovation roadmaps will be discussed.

The Renovation Roadmap for Buildings report commissioned by The Policy Partners includes practical guidance on how building renovation roadmaps can be developed effectively and which elements they should include in order for them to deliver their full potential. [17]
The report sets an indicative time line of targets for a roadmap on national strategy as an example of how targets can be constructed. Targets should cover all relevant aspects of building renovation strategies and reflect how actions, in one year, can build on those in previous years. They also reflect the non-linear character of transitions, which aim to first make deep renovations a common, well-established, efficient practice before large-scale implementation takes place. [17]
Important targets for of the indicative time line have been adopted and are shown in Table 6.

Table 6: Overview of possible targets examples for renovation roadmaps. [17]

Target year	Target
2020	• 5% of all buildings pre-2015 renovated to deep renovation standard: "near zero energy" or high energy performance level.
2030	• 30% of all buildings pre-2015 renovated to deep renovation standard: "near zero energy" or high energy performance level.
2040	• 65% of all buildings pre-2015 renovated to deep renovation standard: "near zero energy" or high energy performance level.
2050	• Energy demand of the building stock reduced by 80% compared to 1990 levels. • All buildings meet "near zero energy" or high energy performance level.

In order to reach the goals set out in Table 6, the BPIE (Buildings Performance Institute Europe) has prepared a guide in which it sets out long term strategies for building stock renovation. This was carried out to assist MS in the process of developing their renovation strategies and in particular the first versions which are to be published by 30th April 2014.
The ambition to achieve greenhouse gas emission reductions of 90% from the building sector compared to 1990 can be reached with the interim milestone targets in 2020, 2030 and 2040. The timeframe of 2050 is consistent with typical replacement cycles of major building equipment and components, which suggest that it will take 30-40 years to substantially renovate national building stocks. This corresponds to a renovation rate of around 2.5-3% annually. This is a significant increase from the current rates of around 1% annually in most European countries. Most renovation activity at the moment achieves only modest energy savings, perhaps 20-30%, but this needs to increase to deep renovations of at least 60% if the full economic potential is to be realised. [18]
Different renovation pathways on the resulting energy and carbon savings have been modelled in BPIE publication “Europe’s buildings under the microscope”. This showed that scenarios where both the rate and depth of renovation was increased considerably, alongside rapid decarbonisation of the energy supply system, could lead to the EU carbon saving ambitions for the building sector. [18]

Figure 6 and Figure 7 indicate the scale of challenge in terms of accelerated activity rates which are needed if the EU is to meet their long-term CO_2 ambitions. The depth of typical building renovation needs to shift from the currently “shallow level” (30% energy saving) to either “deep level” (60-90% saving) or increasingly nZEB for the period 2020-2050.

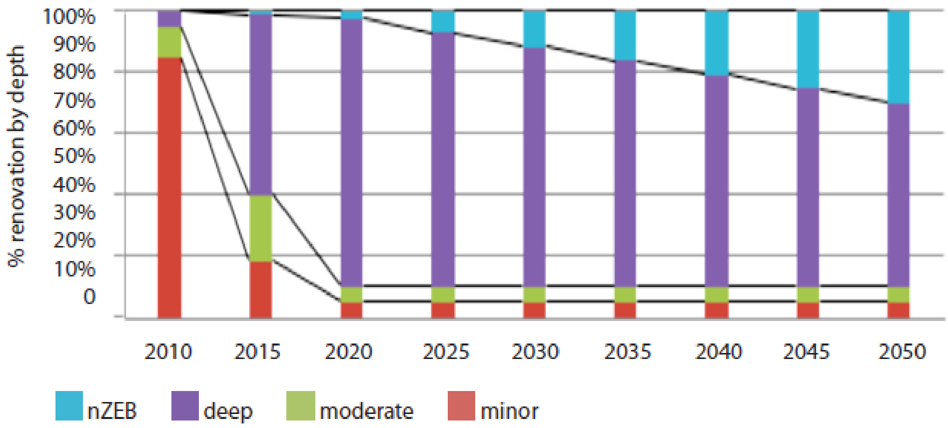


Figure 6: Required increase in renovation depth to achieve 90% CO_2 saving. [18]

At the same time, the renovation rates need to increase from the current rate of around 1% of total floor area renovated annually, to between 2.5% and 3% annually from 2020 onwards.

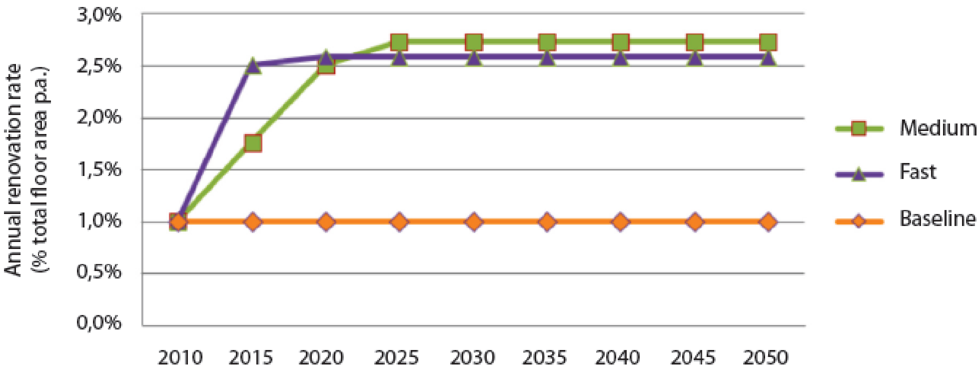


Figure 7: Required increase in renovation rate to achieve 90% CO_2 saving. [18]

The renovation depth and rate, needed for a successful transition towards the CO_2 saving target, have been analysed in “Renovation Tracks for Europe up to 2050” commissioned by Eurima (European Insulation Manufacturers Association). [19]
This study analyses and compares the possible tracks for the renovation of the EU building stock, quantifying and illustrating graphically energy savings and avoided CO_2 emissions, financial impacts and employment effects. The following was concluded:

- A “shallow renovation track” will completely miss both environmental targets (CO_2-emission and final energy savings) while not providing substantial economic advantage;
- A “deep renovation track”, combining a focus on energy efficiency with high use of renewable can be considered as a financially viable route, meeting CO_2-targets while showing the lowest energy consumption and offering the largest job creation potential of the assessed tracks.

Three renovation scenarios for the period to 2050, shown in Table 7, were developed and assessed using the Ecofys’ Built Environment Analysis Model (BEAM). The tracks are characterized by two important parameters: renovation rate (the speed of renovation) and the ambition level regarding energy efficiency improvement and use of renewable energy. The scenarios are set out over a period until 2050; this reveals long term consequences of choices to be made now and in the next years.

Table 7: Renovation tracks for the period to 2050. [19]

Name	Scenario	Description
Track 1	*Shallow renovation,* low contribution from renewable energy	Fast renovation (renovation rate 3%) & average energy efficiency ambition level (~ 32 % reduction in energy use for space heating by 2050 compared to 2010), taking into account market failures (e.g. failure to treat the building envelope as a whole), low use of renewable energy.
Track 2	*Shallow renovation,* high use of renewable energy	Renovation rate 2.3% & average energy efficiency ambition level, taking into account market failures (~ 58 % reduction in energy use for space heating); limited focus on energy efficiency of the building envelope; advanced systems (high use of renewable energy and heat recovery ventilation).
Track 3	*Deep renovation* high use of renewable energy	Renovation rate 2.3%, high level of energy efficiency improvement (~80% reduction in energy use for space heating) high focus on energy efficiency of the building envelope; advanced systems (high use of renewable energy and heat recovery ventilation).

Figure 8 shows the final energy for space heating for EU27 [20] without new buildings. It can be seen that the 80% final energy savings target is a reachable goal. The savings target seems suitable, if it relates to energy used for space heating. The deep renovation track delivers about 75% savings for space heating and domestic hot tap water. It has to be noted that other energy uses, such as energy for cooling, auxiliary energy and lighting, all primarily supplied via electricity, are no considered in this graph.

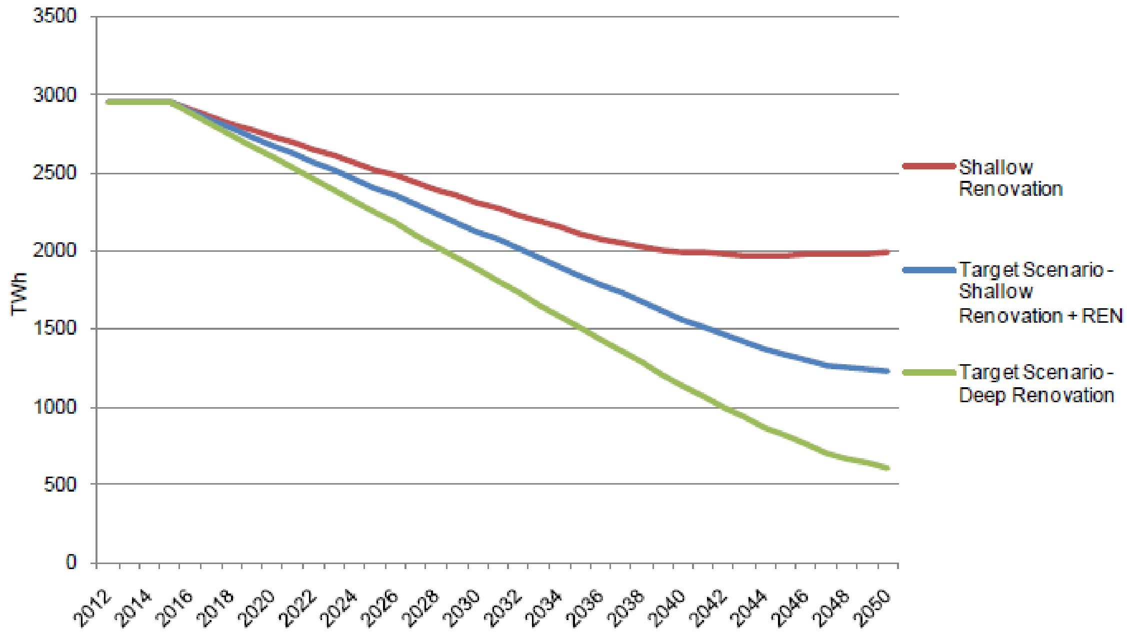


Figure 8: Final energy for space heating in TWh/a for EU27 without new buildings. [19]

2.2 Examples of existing nZEBs in the Netherlands

This sub chapter provides examples of nZEBs in the Netherlands for different buildings types. Focus is on current buildings that satisfy future regulation (2015/2017) and actual nZEBs.

Table 8 and Table 9 show example of nZEBs in the Netherlands and shortly describe the energy saving measures. These buildings have been selected because they apply innovative energy technologies that are interesting for the nZEB scenarios in this report. They are also selected based on their energy performance (EPC score). The following buildings are shown:

- 8 residential buildings (Table 8):
  - Terraced and detached houses with an EPC ≤ 0.4 (2015 regulation)
  - Apartments with an EPC ≤ 0.6
- 8 utility buildings (Table 9):
  - 4 office buildings with an EPC ≤ 0.7
  - 4 school buildings with an EPC ≤ 0.4

More information on nZEB buildings in the Netherlands can be found:

- Agency NL website: database with energy efficient buildings in the Netherlands. [21]
- Article: W. Zeiler - Dutch efforts for a Sustainable Built Environment (TU/e). [22]
- Agency NL brochures and reports on nZEB for residential buildings, office buildings and schools. [23][24][25][26]

More detailed information on a residential building, an apartment block, and a utility building can be found in Appendix II. The selection of these buildings is based on the reference buildings a-c listed in the EPBD (chapter 1.2). One of the UKP NESK school projects, partially designed by RHDHV, is also discussed in Appendix II.

Table 8: Overview of residential buildings in the Netherlands. [23][27][28][29][30][31][32][33][34][35][36]

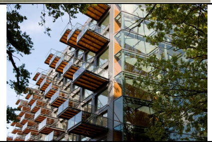
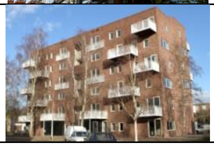
Overview Dutch residential nZEBs					
	Project	*Type*	*Year*	*EPC*	*Energy saving measures*
	W&R Groenwoning, ‘s Gravenzande	Semi detached	2011	0.32 – 0.35	Isolation and triple glass combined with a large solar collector (10 m^2) boiler system (600 litres) which covers energy needs for 80%. Combined ventilation: natural air supply with automatically controlled vents, mechanical air outlets. Night cooling in summer.
	Passive house renovation Sleephellingstraat, Rotterdam	Terraced	2009	0.4	Renovation of 14 historic city dwellings. Very good insulation (R_c = 10 m^2K/W), triple glass and maximal air tightness reduce energy loads. High efficiency boiler in combination with solar boiler system. Balanced ventilation with heat recovery.
	Passive houses Velve-Lindenhof, Enschede	Terraced	2010	0.35	80 passive houses with a combined solar collector system providing hot tap water. Conventional high efficiency boiler for heating, combined with balanced ventilation with heat recovery. Very good insulation (R_c = 8-10 m^2K/W) and triple glass reduce energy demand to a minimum. PV panels have also been applied.
	All-electric proeftuin Hunzedal, Borger	Terraced	2012	0.25	28 dwellings are provided with all-electric energy facilities (installations, appliances). The houses have very good ventilation, a GSHP, low temperature heating, balanced ventilation with heat recovery, a shower heat exchanger, and a large PV panel installation (28 m^2).
	CO_2- neutral street, Grijpskerke *(Appendix II)*	Terraced	2011	0.01	Good insulation (R_c = 5.0-8.5 m^2K/W) and triple glass. Individual GSHP with direct evaporation and floor heating. Indirect gas fired boiler with a solar collector (2.5 m^2) Balanced ventilation with heat recovery (95). Large PV panel surface (20-27 m^2).
	Energie-evenwicht woningen Rijsdijk, Etten-Leur	Detached	2002	0.00	22 energy neutral dwellings realized by a large roof surface oriented south, allowing maximum benefits for the solar collector (combined with GSHP) and a large PV system (50 m^2). Heating and cooling is provided by an individual GSHP. Good insulation, air tightness and balanced ventilation with heat recovery (95%) reduce energy demand.
	Kotmanpark, Enschede *(Appendix II)*	Apartment	2011	0.48	Passive design concept has been applied: apartment building is oriented south, good isolation (R_c = 7-10 m^2K/W), high air tightness and prevention of heat bridges. A combined solar collector and GSHP system proved heating, cooling, and hot tap water. Monitoring systems provides feedback about energy consumption for residents.
	Geert Grote Straat, Zwolle	Apartment	2012	0.6	A light weight steel construction is used to ensure low thermal mass. Collective GSHP provides heating and cooling, with a high efficiency heater for winter. Very good insulation (R_c = 7-10 m^2K/W), triple glass, good air tightness, and balanced ventilation with heat recovery reduce heat demand.

Table 9: Overview of UKP NESK projects (offices and schools) in the Netherlands. [24][25][26][37][38][39]

Overview Dutch UKP NESK projects offices and schools					
	Project	*Type*	*Year*	*EPC*	*Special features*
	TNT Centre, Hoofddorp	Office ($17{,}000\ m^2$)	2010	0.67	All-electric building where heating and cooling is generated with a bio heat power combination together with a heat pump connected to aquifer storage. The building is compactly built, utilizing solar light to a maximum (external heat gains, advanced day lighting systems). Hot tap water is provided by a solar collector system.
	Villa Flora, Venlo	Office ($12{,}000\ m^2$)	2011	0.38	Technology from greenhouses is applied using a heat pump with 4 different sources: aquifer storage, heat extraction from air in the atrium, heat recovery from ventilation air, and cold from a 'smart skin' facade. Hot tap water is provided by a small bio-digester, running on bio waste. Use of PCM's and 1000 m^2 PV ensures a good EPC score.
	Provinciehuis Noord-Holland, Haarlem	Office ($19{,}000\ m^2$)	2012	0.5	Office renovation resulting in EPC drop from 1.7 to 0.5. Energy demand reduced with: good insulation (R_c = 6.0 m^2K/W), triple glass, low energy smart light system, and balanced ventilation with heat recovery. Heat and cold storage also applied.
	Zeswegen, Heerlen	Office ($17{,}500\ m^2$)	2012	0.56	Local mines are used for heat and cold storage applying a GSHP. Energy demand is minimized by good insulation (R_c = 4-5 m^2K/W), triple glass; overhang solar shade, mechanical ventilation with heat recovery and a PV panel surface of 1500 m^2.
	Hart van Oijen, Oijen	School ($2{,}400\ m^2$)	2012	0.4	An energy neutral school realized by applying a biogas-CHP. Biogas is provided from a nearby manure digester. Heating and cooling is combined with collective heat pumps, with heat and cold storage. The building is design on basis of passive solar energy principle with a 150 m^2 PV panel surface.
	Focus-Huygens College, Heerhugowaard	School ($4{,}300\ m^2$)	2012	0.0	Energy neutral based on applying Passive house-concept. Very good insulation (R_c = 10 m^2K/W) and triple glazing reduce energy demand. Heat and cold storage is applied in combination with ventilation with heat recovery. Large scale application of PV panels.
	MFC Brede School, Westergeest	School ($1{,}800\ m^2$)	2012	0.0	A compact building designed for optimal solar gains: day lighting design (light domes, light shelves) minimizing need for lighting, large PV panel surface (1200 m^2) and solar collector (tap water). The building has a wooden structure with concrete elements that are hollow. Heating and cooling provided by a closed GSHP system.
	DSK-II, Haarlem *(Appendix II)*	School ($2{,}700\ m^2$)	2012	0.0	Energy neutral innovative technologies: heat of a central computer server room is used for heating and hot water, the dishwasher uses heat recovery making it more efficient. Heat and cold storage in combination a large PV panel surface (820 m^2) ensure good building energy performance.

2.3 Comparison between current buildings and nZEBs

This sub-chapter compares building properties of current buildings, future buildings and nZEBs in the Netherlands. The focus will be on building construction and building installations for three building types, based on the reference buildings a-c listed in the EPBD (chapter 1.2):

- single family house;
- apartment block;
- office building.

The nZEBs will be compared with a buildings according to current regulation (2013) and future regulation ('Lente Akkoord' for 2015/2017) as shown in Table 3.
For the single family house and the apartment block similar reference buildings (from Agency NL) have been used. For office buildings different types (size, geometry, etc.) will be compared. The geometry, layout and dimensions for the single family house and apartment block can be found in Appendix III.
All three building types will be compared to each other in a table; important differences will be discussed. The main focus will be on construction aspects (R_C and U values) and building installations for heating, cooling, hot tap water and ventilation.

2.3.1 Single family house

The reference building is a terraced house which is situated in between other dwellings (no corner house). Terraced houses represent approximately 50% of all newly built buildings in the Netherlands. Almost three quarters of terraced houses is an in-between-dwelling ('tussenwoning'), which is 36.5% of the Netherlands. 80% of the terraced houses are owner-occupied buildings and 20% are within the renting sector. A typical in-between-dwelling consists of three bedrooms and is mostly fitted with a saddle roof. [40]
The geometry and dimensions of all dwellings (current, future, and nZEB) are equal: the total user surface of the building is 125m^2 (Appendix III).

The three reference buildings are compared in Table 10. The buildings have comparable construction types; however the nZEB has considerable higher R_c-values (5.0 m^{2}K/W for walls/floors and 6.0 m^{2}K/W for the roof) and lower U-value compared to the current and future building.
The current and future building have a combined heating and hot tap water system powered by a solar collector with pre- and after heater, but with different generation efficiencies, to comply with an EPC of 0.6 and 0.4. For the nZEB a high efficiency boiler is used for low temperature (floor) heating and the hot tap water is provided by a solar collector system. All three buildings have floor heating and no cooling is applied in all buildings.
The nZEB has additional electricity generation provided by mono crystalline solar cells with an area of 25m^2. All three houses have the same balanced ventilation system in which the dwelling is ventilated via a central unit. Air is supplied in the living room and the bedroom and discharge in the kitchen, toilet and the bathroom. The ventilation system has a complete bypass (for summer situation) and a heat recovery efficiency of 95%.

Table 10: Comparison of 'in-between-dwellings' terraced houses in the Netherlands. [41][42][43]

	Current building	**Future building**	**nZEB**
EPC demand (year)	0.6 (2013)	0.4 (2015)	≈ 0 (2020)
Construction			
R_c value [m^{2}K/W] for: - Walls - Roof - Floor	 3.5 4.0 3.5	 3.5 4.0 3.5	 5.0 6.0 5.0
U-value [W/m^{2}K] for: - Windows and frame	 1.65	 1.65	 1.00
Installations			
Heating	Solar collector system (2.3 m^2) with pre- and after heater	Solar collector system (2.3 m^2) with pre- and after heater	High efficiency gas boiler (107HR) with central heating
Heating generation efficiency	1.340	2.430	0.975
Cooling	No cooling system	No cooling system	No cooling system
Hot tap water	Combined with heating system	Combined with heating system	Solar collector system (5.5 m^2) with pre- and after heater
Hot tap water generation efficiency	0.700	2.425	0.825
Ventilation	Mechanical (supply and discharge)	Mechanical (supply and discharge)	Mechanical (supply and discharge)
Electricity generation	-	-	PV system (25.5 m^2)
EPC	0.59	0.4	0.01

2.3.2 Apartment block

Apartment blocks represent about 33% of the newly built building in the Netherlands. Two thirds of the apartment blocks are owner-occupied buildings and the rest is covered by the renting sector. [40]
An apartment usually has two bedrooms and an average user surface of 92 m^2. Within this average surface simple gallery complexes (renting sector) have been accounted as well as more luxurious apartments (generally buying sector).

The reference building for all cases is an apartment complex with 4 stories and 6 apartments per floor (Appendix III). The three reference buildings are compared in Table 11. The R_c-values for all apartments are the same as for the terraced houses, but the U-value is already lower for current and future building (1.0 W/m^2K).
For the current and future apartment block a shared solar collector system with pre- and after heater is used for heating and hot tap water. In addition a shower heat exchanger is used to reduce hot water demand for showering; this feature is used for all three cases. The nZEB uses a high performance boiler for heating and a shared solar collector system for hot tap water. All three buildings have floor heating and no cooling is applied.
The nZEB apartment block has additional electricity generation provided by mono crystalline solar cells with a total area of 444 m^2.
The ventilation system is same for all apartments and identical to that of the terraced houses.

Table 11: Comparison of apartment blocks buildings in the Netherlands. [44][45][46]

	Current building	**Future building**	**nZEB**
Minimum EPC demand	0.6 (2013)	0.4 (2015)	≈ 0 (2020)
Construction			
R_c value [m^2K/W] for: - Walls - Roof - Floor	 3.5 4.0 3.5	 3.5 4.0 3.5	 5.0 6.0 5.0
U-value [W/m^2K] for: - Windows and frame	 1.00	 1.00	 1.00
Installations			
Heating	Shared solar collector system (62.1 m^2) with pre- and after heater	Shared solar collector system (62.1 m^2) with pre- and after heater	High efficiency gas boiler (107HR) with central heating
Heating generation efficiency	1.340	2.430	0.975
Cooling	No cooling system	No cooling system	No cooling system
Hot tap water	Combined with heating system, with shower heat exchanger	Combined with heating system, with shower heat exchanger	Shared solar collector system (148.5 m^2) with pre- and after heater with shower heat exch.
Hot tap water generation efficiency	0.700	2.425	0.700
Ventilation	Mechanical (supply and discharge)	Mechanical (supply and discharge)	Mechanical (supply and discharge)
Electricity generation	-	-	PV system (444 m^2)
EPC	0.54	0.4	0.16

2.3.3 Office building

Three different office buildings (size, geometry, etc.) will be compared. All buildings (current, future and nZEB) will be discussed separately and compared in Table 12.

Current building

For newly built office buildings current EPC demands of 1.1 exists. Using the guidance from Agency NL, reference specifications for buildings that have to comply with current regulation have been used. The reference building has a user surface of approximately 15.000 m^2 and windows to wall ratio of 2 (~ 35% windows). [47]

Heating is provided by a high efficiency boiler. Limited cooling is provided by a balanced ventilation system including a heat regeneration system with efficiency 70%. An electric boiler is used for hot tap water.

The building is well insulated using R_c values of 3.5 m^2K/W for walls and floor and 4.0 m^2K/W for the roof. For the windows HR++ glass is used.

A smart lighting system, including daylight sensors and presence sensor, further reduce energy consumption.

Future building

The Eneco headquarter office building (Picture 1) is an energy efficient building in Rotterdam (next to the RHDHV office), designed by Architecten Dam en Partners, built with project developer OVG and technical specialist Reynaers and Oskomera. The office has a total floor space of 25,000 m^2 to accommodate 1400 working people. [48]

An energy efficient building has been created by using an underground heat and cold storage system and application of large solar PV integration. The GSHP is assisted by district heating in the winter, when necessary. On the south side of the building a façade surface of 500 m^2 has been covered with PV cells. Furthermore advanced sun-trackers (solar panels that follow the sun's direction) and horizontal panels are installed on the roof of the building. This adds up to a total of more than 1100 m^2 of solar cell surface. [49]

The energy efficient measures have created an office building with an EPC of 0.72. Other aspects that make this building more sustainable are roof gardens, a vegetation façade on the bottom 3 floors and charging poles for six electric cars.

The facade/floor and roof are well insulated with R_c-values of 4.0 m^2K/W and 5.0 m^2K/W, respectively. Glass with aluminium frames with a total U-value of 1.1 W/m^2K is used. [50]

Picture 1: Eneco headquarter in Rotterdam. [51]

nZEB

The regional Enexis office in Venlo built in 2012 is one of three new offices (also Maastricht and Zwolle) with an excellent building performance. Atelier PRO is responsible for the design, while Deerns has developed the technical installations. The office has been designed as a Zero Energy Building with an EPC of 0, made possible by 2100 m^2 of PV-cells. [52][53]

The building is very well insulated using prefab façade elements with R_c-values between 6.0 and 8.0. Different types of windows (U- value between 1.7 and 0.9) have been applied to optimally use solar radiance were needed and reduce unwanted external gains. [54]

Heating and cooling is provided by a ground source heat pump an additional high efficiency boiler during cold days. Floor heating is used a release system and by applying thermal wheel within the ventilation system, heat is regenerated to the building. Furthermore a bypass ensures no overheating occurs during the summer.

Other aspects that make this building very energy efficient are: climate ceilings, energy efficient lighting, day light control and presence detection.

Picture 2: Enexis office in Venlo. [55]

Table 12: Comparison of office buildings in the Netherlands. [47][48][50][52][53][54]

	Current building	**Future building**	**nZEB**
	Agency NL reference building	Eneco office (Rotterdam)	Enexis office (Venlo)
EPC demand (year)	1.1 (2013)	0.7 (2017)	≈ 0 (2020)
Year of construction	-	2011	2012
User area [m^2]	for ≥ 15,000	25,000	5,430
Construction			
R_c value [m^2K/W] for:			
- Walls	3.5	4.0	6.0 – 8.0
- Roof	4.0	5.0	6.0
- Floor	3.5	4.0	6.0
U-value [W/m^2K] for:			
- Windows and frame	1.2 (HR++ glass)	1.6	1.70 – 0.90 (double and triple glass)
Installations			
Heating	High efficiency gas boiler (107HR)	Electric heat pump (hot wells) with district heating	Electric heat pump (hot wells) with high efficiency boiler (HR107)
Cooling	Compression cooling	Electric heat pump (cold wells)	Electric heat pump (cold wells)
Hot tap water	Electric boiler	Electric boiler	Solar collector system (10 m^2) with electric (close-in) boiler
Ventilation	Mechanical (supply and discharge) with heat recovery (≤ 70%)	Mechanical (supply and discharge) with heat recovery (sorption wheel)	Mechanical (supply and discharge) with heat recovery)
Electricity generation	-	PV system (1140 m^2)	PV system (2100 m^2)
EPC	0.6	0.72	0.0

3 nZEB potential in the Netherlands

The potential for nZEBs in the Netherlands depends to a large extent on the infrastructure and the available building energy technologies. The Dutch energy infrastructure (Ch. 3.1) is discussed to understand current and future status of the gas and electricity network. Furthermore an overview on smart grids in the Netherlands is shown which gives insight for nZEBs districts and infrastructure. At the end (Ch. 3.2) building energy saving measures are listed in an overview: an indication is given for which area these measures are interesting.

3.1 Energy infrastructure

An important aspect for nZEBs is the energy infrastructure in the Netherlands. Energy neutral buildings have different load patterns on the gas and electricity network compared to conventional buildings, depending on technical installations used. This sub-chapter describes the current and future status of the energy infrastructure and gives examples of smart grids.

First a short sketch is given on the changing energy infrastructure in the built environment. Figure 9 shows the vision on energy infrastructure from a RHDHV study on nZEBs in the built environment. In current situation single buildings are connected to energy generating infrastructure (red circle) and Long Term Energy Storage (LTES) systems (blue circle).
Future energy infrastructure will be connected on a local level, with an integrated smart grid (energy exchange between buildings). The energy infrastructure has to be able adapt to changing conditions such as; changing building functions during the lifetime of the building, future extension of buildings, etc. These effects have to be incorporated into the energy infrastructure of the future to ensure a stable network.

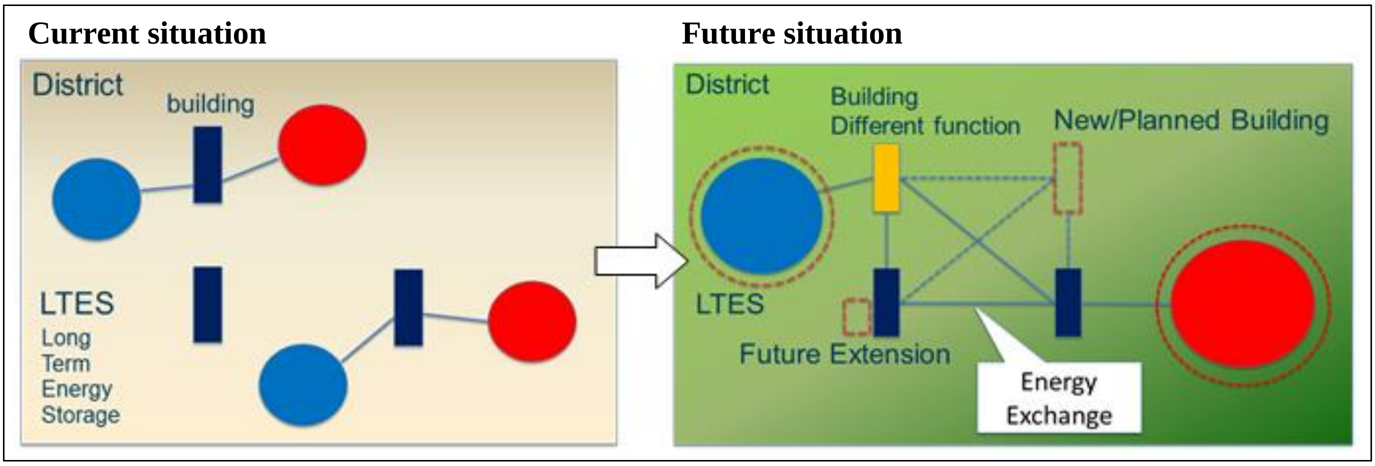


Figure 9: Current and future energy infrastructure in the built environment. [56]

3.1.1 Gas infrastructure

The Netherlands has a good gas network infrastructure and is currently the largest gas producer in the EU and is expected to be a gas exporter until 2025. The gas field in the province Groningen provides energy to the Netherlands (buildings and industries) and other European countries. The Dutch government wants to keep playing an important role after 2025 by becoming a gas importer. Much knowledge and expertise is available in the Netherlands due to long experience with gas. The Dutch government has plans to improve the gas network and storage to become North-West Europe's 'gas-roundabout'. [57]

The Dutch gas network has good potential to contribute to more sustainable gas transport by providing ‘green gas’ from biomass. Green gas is a clean and sustainable variant of natural gas and is made from upgraded biogas. Biogas is produced from sludge, waste from landfills, yard waste, fruit and vegetable waste, and animal waste products such as cow manure. This biogas is not the same as green gas, as it has a lower quality. To obtain biogas with the same level of quality as green gas, it has to be purified (CO_2 removal and other contamination), dried and upgraded (odorisation, pressured) to the same quality. Green gas can be mixed with natural gas and distributed in the Dutch national gas network. [58]

Green gas projects

The Dutch government has started 10 Green Gas Projects (GGP) spread over the country to gain knowledge and determine the feasibility of large scale application in the Netherlands. The past 20 years about 30 million Nm^3 green gas has been produced and supplied to the national gas network. Most of these projects use Combined Heat Power (CHP) systems to generate heat and electricity locally. It is projected that in 2020 about 1 million homes can be proved with sustainable gas. [59]

GGP have been increasingly more interesting over the last few years because of the so called SDE-arrangement (Stichting Duurzame Energieproductie, translated as Foundation of Sustainable Energy Production). The SDE arrangement supports these projects financially; subsidies are handed for all sorts of biogas production installations. [60]

The feasibility of GGP is for each specific project strongly depends on the economic considerations and the local situation. Especially the distance from the green gas production site to the gas infrastructure and the production capacity play a key role. Connection to the national gas network (40 bar) is much more expansive than the regional network (8 bar). Because of the high network connection costs initiative are deployed for the development of green gas-hubs. These hubs are a central point where biogas is converted to green gas and supplied to the national gas network. [59]

To determine the long term feasibility of biogas and green gas, two sources have been consulted.

Authors of a Rabobank brochure on the role of biogas in Europe and the Netherlands, state that biogas application is to a large extent dependent on local conditions, local heat (and electricity) demand, network infrastructure (transportation) and subsidies. The applications of biogas have been displayed in Table 13 comparing the energy efficiency, reduction of greenhouse gasses and economic outcomes before subsidies. It can be concludes that the most promising energy product is solely heat, because of its high efficiency and best economic returns. [61]

Table 13: Evaluation of biogas energy products. [61]

Evaluation of biogas versus type of end product	Energy efficiency	Reduction of greenhouse gasses	Economic benefits excluding subsidies
Electricity production	Low ~ 40%	Average - dependent on biomass material	Unattractive
Combined electricity and heat production (CHP)	High ~ 60-80%	Average to high - dependent on biomass material	Unattractive to average
Heat production	High ~ 100%	Average to high - dependent on biomass material	Most attractive
Injection into the national gas network	Average ~ 80%	Average to high - dependent on biomass material	Improved
Fuel for transport usage	Average ~ 65%	Average to high - dependent on biomass material	Improved

The costs of biogas production are driven by increasing raw material prices; prices of agricultural material have doubled since 2000 and it is expected that this increasing trend will continue. Biomass materials have become more expansive because of rising demand and stimulating measures from the government. In the Netherlands most biogas plants are uneconomical to run because the raw material prices have risen so sharply in recent years, according to the benchmark of Rabobank. In Germany increased corn prices have led to cancelation of different biogas projects in 2012. [61]

A paper investigated the economic feasibility of producing 17 PJ green gas for two business models (stand-alone and central upgrading) in the province Overijsel in the Netherlands. [62] From this study was found that the probability that the combined business models reach their production capacity results in a negative NPV of 23%. The sensitivity analysis showed that biogas yield and investment cost have significant effects in determining the NPV values.
When looking into the risk profile of green gas production, concerns arise such as: the availability of feedstock, the location of digesters, availability of subsidy, and stability of government policies on renewable energy (SDE subsidy).
Published ambitions by the government envision a share of 8-12% of green gas in 2020, 15-20% in 2030 and 50% in 2050. To reach these future targets a share can be produced from co-digestion of manure and agricultural crops. This potential has not yet been exploited, but if in the long term other food chains would aim in becoming an energy-neutral chain, availability of feedstock (particularly the co-digestion materials) will be a bottleneck. In addition to concerns about availability of feedstock, digesters should be strategically located based on local availability of manure and other feedstock as long distance transportation of feedstock would hamper the economic and environmental sustainability of the plant.
Regarding policy on renewable energy, due to frequent shifts in policy the Dutch government has failed to build confidence in the stakeholders and has failed to reduce market uncertainties.

3.1.2 Electricity grid

The climate goals towards 2020 and 2050 will have a great impact on the way the electricity grid is used in the Netherlands and the rest of Europe. The transition from a supply-demand system (using fossil fuels) towards a supply-dependent system (using fluctuating renewable energy sources) will have major consequences for the infrastructure and operation of the network. ‘Smart grids’ in combination with thermal and electrical storage systems will have to be applied more to cope with the fluctuating characteristics of wind and solar energy.

Netbeheer Nederland is a branch organization of large energy (electricity and gas) companies in the Netherlands including Alliander, Cogas Infra en Beheer, Delta Netwerkbedrijf, Edinet, Enexis, Gasunie, Liander, Rendo, Stedin, TenneT, and Westland Infra Netbeheer. Together they have created a document were possible developments in the Dutch energy infrastructure and the role that network operators have to play in the transition are explored. [63] Interesting issues from this report, concerning nZEBs, will be discussed in the following paragraphs.

One of Netbeheer Nederland studies suggest, that at this moment it is not possible to predict which investments will be required, how large they will need to be and where and when a start should be made. There is a considerable risk that any investment decisions made now to facilitate energy transition will, with hindsight, be inappropriate. For energy infrastructure in the Netherlands, the study indicates a number of quite plausible consequences [63]:

- The CO_2 reduction targets imply that at the local level only CO_2-neutral carriers of energy can be supplied, for example electricity (generated from sustainable or 'clean' fossil fuels), green gas and (heated) water. The increase in decentralized generation means that the capacity of local power networks in new and existing housing estates and buildings will need to be increased and made 'smarter'.
- Local distribution of natural gas will change notably. It is expected that demand for natural gas will decline partly as a result of efficiency measures and partly because gas as a source of heating by will be replaced by other sources such as GSHPs, solar boilers, heat pumps, waste and process heat from fossil-fuel-fired power stations combined with Carbon Capture Storage, green gas, micro-CHP units fired with green gas, and bio-CHP at a district or central level. Jointly-owned systems are likely to play a more important role than they do now due to their economic advantages. Natural gas may still play a role in meeting peak demand for heating: related CO_2 emissions are relatively small.
- At the local level, gas distribution networks will increasingly distribute green gas. Ultimately, in new building projects the distribution of gas and heat to all buildings will cease. The pace of this change will depend on the speed at which building standards for emission-free buildings with an EPC of zero (ZEBs) are introduced and on the outcome of the discussion as to whether gas will or will not continue to play a role in meeting peak demand for low-level heating.

A roadmap towards smart grids has been made by Netbeheer Nederland to provide a working agenda which outlines the role of smart grids in three future scenarios for 2050. Three scenarios concern the following levels: residence level (micro level), neighbourhood level (meso level) and Dutch national energy system (macro level). Views on the mirco and meso level will be shortly discussed. [64]

Smart grids at micro level

New houses will be energy-neutral and most existing residences been well insulated by 2050. The average energy consumer is also an energy producer due to the installation of solar panels, high efficiency combo furnaces that generate electricity (primarily for older houses in which the possibilities for insulation are limited), etc. A number of storage options have been provided, both for electricity (e.g. batteries of electric cars or small battery systems) as well as in the form of heat storage (e.g. hot water tank). The energy system is optimized using an energy management console, which is present in every house.

It is expected that consumers have the opportunity to contribute themselves to improving the sustainability of the energy supply and energy transition. The new infrastructure provides consumers with new services that contribute to an increase in comfort at lower costs. For instance, price-related energy services (shifting loads to avoid the expensive peak times, energy supply related to current production information about renewable sources, etc.) as well as energy services that increase comfort (switching on and off space heating on the basis of demand instead of fixed clock times).

Smart grids at macro level

At the neighbourhood level (district with ~ 1000 residences) smart grids make more autonomy possible. Due to the mutual energy exchange between residences in combination with local production (CHPs at the neighbourhood level), GSHP and biogas installations are making neighbourhoods increasing self-sufficient, although full independence of the system will probably not take place. Possibilities for electricity storage are also provided in the neighbourhood. There are also sufficient fast charge points for electric cars.

Neighbourhoods will vary in terms of energy concept: some neighbourhoods are all-electric, others have both electricity and gas infrastructure and other neighbourhoods combine the electricity infrastructure with district heating.

Both reports from Netbeheer Nederland show potential for (combined) CHP systems and GSHP systems, and PV-systems for electricity production.

3.1.3 Smart grids

This section first discussed the definition of smart grids is which is followed by an overview of smart grid projects in the Netherlands.

There are many smart grid definitions: functional, technological or benefit-oriented. Most definitions appoint the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. One of the key issues in the design of smart grids is the ability to use integrated digital technology with power grids, and integration of the new grid information in utility processes and systems. [65] The power grid is usually referred to as an electricity grid, but can also refer to a heat network or gas infrastructure.

The definition of a smart grid used in this report is:

> *A smart grid is a power grid that uses analogue or digital information and communications technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of an energy carrier such as electricity, heat (hot water), natural gas.*

Smart grids may vary in structural designs, but common features of smart grids exist [65]:

- *Reliability*; improved by fault detection, allowing self-healing of the network without intervention of technicians.
- *Flexibility*; networks will be able to handle bi-direction energy flows, convenient for decentralized small scale power generation.
- *Efficiency*; energy and financial efficiency by less redundancy in transmission and distribution lines, greater utilization of power generators, leading to lower prices.
- *Peak levelling and time of use pricing*; reduce peak loads by matching supply and demand of energy, enabled by price incentives.
- *Sustainability*: improved flexibility allows intermittent sustainable energy sources to be implemented in the grid, with or without the addition of energy storage.
- *Market-enabling*: more sophisticated and flexible operational strategies for suppliers and consumers because of communication and metering systems.

Smart grid projects

Currently in the Netherland different smart grid projects are carried out. These projects range from local smart grids for residential districts and business parks, to initiatives to create an electrical storage system for electric taxi services.

Figure 10 shows an overview map of smart grids projects currently in progress. Table 14 shows the project name, location and a short project description related to Figure 10. More information on these smart grid projects can be found at the following sources:

- Website: Netbeheer Nederland. [66]
- Document: Agentschap NL - Proeftuinen Intelligente Netten 2011-2015. [67]
- Website: Agency NL, factsheets on latest status of smart grid projects. [68]

Figure 10: Smart Grid projects in the Netherlands. [66]

To gain some more insight in smart grids and determine the implications for nZEBs, three projects will be discussed in Appendix IV. The projects discussed are:

- Bio Energy Vallei
- Power Matching City
- Your Energy Moment

These specific projects are discussed because they include residential areas on different scale: 25 dwellings, 266 dwellings and 3000 dwellings. Different renewable energy sources are used (PV panels, GSHP, biomass heat) and also different types of network (electrical and heat) are applied.
The examples discussed in Appendix IV give a good impression on how future infrastructure for suburban areas may look like. Scenarios of infrastructures for nZEBs in three different areas (urban, suburban, rural) will be discussed in Ch. 4.2.1, Ch. 4.3.1 and Ch. 4.4.1.

Table 14: Smart Grid projects in the Netherlands. [66][67][68]

Smart Grid Proeftuinen in the Netherlands			
	Project	*Location*	*Description*
1	The Grounds	Schiphol	A large scale organization (29 participating companies called ProSECco = Proeftuin Smart Energy Collective & Co) focused on preparing electricity networks on two-way direction and monitoring (understanding) and stimulating consumer behaviour.
2	Duurzaam Heijplaat	Rotterdam	Residential district adapted for local energy exchange, combined with feedback systems, price incentives and active control.
3	Texel Energie	Texel	Smart meters used to provide Texel residents insight in electricity consumption. Gas network leaks are mapped with smart gas meters.
4	Intelligent energienetwerk	Deventer	Local intelligent medium-voltage (10 kV) and thermal network for a business park with local renewable energy production.
5	PrimAviera	Haarlemmer-meer	A direct current network for local farmers and greenhouses producing electricity with wind, PV and CHP.
6	PowerMatching City 2	Hoogkerk	Smart grid for 30 to 50 dwellings, combined with two smart distribution transformer and 20 EVs.
7	Campus TU Delft	Delft	Intelligent heat network combining heat and cooling demand in the built environment with the existing heat-cold network.
8	Appartementencomplex Couperus, Smart Grid	Den Haag	Apartment complex (300 dwellings) with a collective heat and cold storage with individual heat pumps.
9	Muziekwijk, Jouw Energiemoment	Zwolle	Smart grid for 266 dwelling in a residential district combined with PV panels, EV's and smart appliances.
10	Smart Grid Rendement voor iedereen	Utrecht en Amersfoort	Innovative local dynamic energy management system monitoring two residential districts to gain info on electricity supply/demand networks.
11	Social Energy	Utrecht en Den Haag	Research on demand control carried out using smart meters in two residential districts. Energy consumption is compared by participants.
12	Jouw Energie Moment, Easy Street en Meulenspie	Breda	Renewable energy production combined with smart meters gives participants insight in the supply/demand of energy in their dwelling.
13	Inteligent MS-net	Tholen	MS-installation for measurements and communication techniques.
14	All-Electric nieuwbouwwijk	Gorinchem	ProSECco (see 1.) for an all-electric residential district. Monitoring technologies: heat pumps, PV panels, EV's
15	Stad van de Zon	Heerhugowaard	ProSECco (see 1.) for a residential district with large scale PV application. Focus: balancing electricity supply and demand.
16	Waterstad Goese Schans	Goes	ProSECco (see 1.) for a local smart heat and electricity network.
17	Smart Storage, De Keen	Etten-Leur	Electricity storage for 200 dwellings during peak PV production
18	Evander	Nieuwegein	Electric Vehicles and Distributed Energy Resources (EVANDER) Smart electricity network developed to store locally produced renewable energy for EVs, connected to a business park.
19	Livelab Gas	Zutphen	Local gas network which is monitored and optimized, reducing gas network loss so more decentralized gas feed-in is possible.
20	Inteligent net in duurzaam Lochem	Lochem	A local smart grid which integrates decentralized electricity generation, EV application and storage and data systems.
21	Cloud Power	Texel	Cloud Power facilitates local communities, concerning 300 dwellings, to match supply and demand of localized power production (wind, PV).
22	Greenport Venlo, bedrijfventerrein	Venlo	An integral energy supply network for greenhouses is constructed to optimize energy supply/demand and infrastructure.
23	Houthaven Amsterdam, stadsdeel West	Amsterdam	Energy neutral block is built by: energy saving (70%), local renewable energy (22%), and saving on behaviour and ICT solutions (8%)
24	Bedrijvenpark A1	Deventer	Intelligent electricity and heat network for a business park. (see 4.)
25	Twenergy	Almelo	Complete or partial self-sufficiency in heat and electricity network powered by CHP production facilities on biomass, waste, or manure.
26	Cogas Slimme Meter App	Oldenzaal	Smart meter combined in an application for consumption overview.

3.2 Building energy saving measures

This sub-chapter gives an overview of energy saving measures for buildings in three specified areas: urban area, suburban area and rural area. The goal is to present relevant building technologies for the nZEB scenarios in chapter 4. The focus is mainly on installations using renewable energy sources; these measures are described in detail in Appendix V.

Before building energy saving measures are described, first strategies focusing on energy saving measures concerning building users are shortly discussed.
Figure 11 shows a schematic representation of reduction of energy demand by focussing on building user needs. The general approach to improve building energy performance is by reducing energy demand with passive measures and building energy saving measures; however considerable energy reduction could be accomplished when the thermal systems are customized for each building user specifically.
Techniques that focus on building users are: (individual) climate zones, workplace thermal systems, presence detection, etc. Also prediction of user behaviour (for example in building performance simulation) will become more important in order to better match user energy demand to building installations.

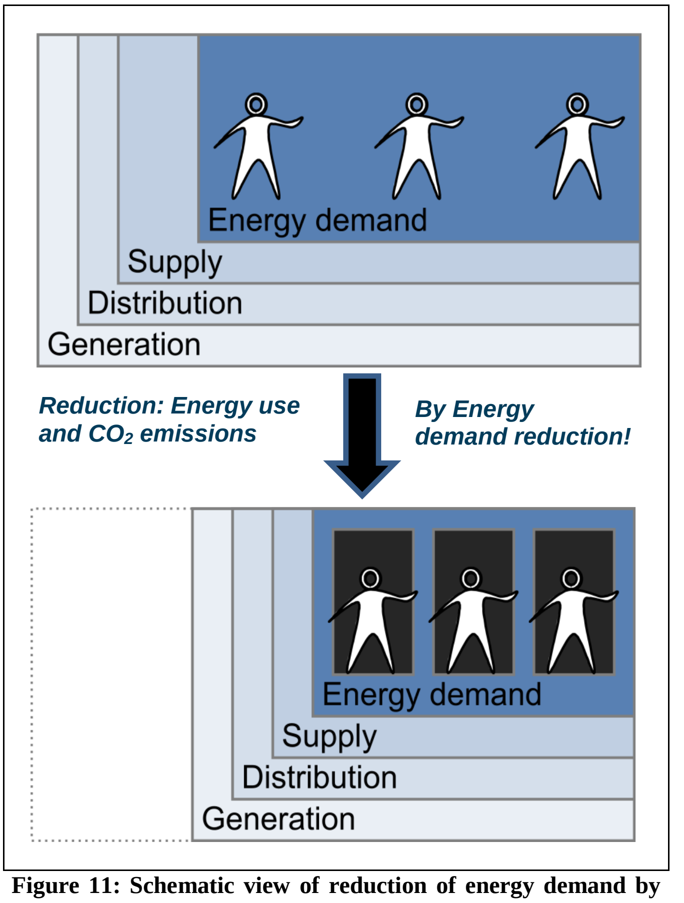


Figure 11: Schematic view of reduction of energy demand by focusing on building user needs. [56]

According to a study on human centred energy control, more than 20% energy savings can be achieved on heating demand and up to 40% energy savings on cooling demand compared with the actual energy demand. [69] The study showed a strong correlation between the occupancy (of a floor in an office building) and the most important human influence on building performances, use of electrical appliances.

Research about control strategies for indoor air temperature in a conditioned system (offices) describes a method based on individual's feeling of comfort instead of traditional fixed indoor air temperature control method. [70] Combined with human's psychological reaction and the new signal transfer technique, the room air temperature is controlled by the signals sent from human body so that the individual's actual requirement is satisfied without compromise. The writers suggest using the temperature of the wrist skin at inner side as the representative index to control the air conditioning system.

Energy saving measures focussing on building user needs are very effective and necessary to achieve significant reduction in primary energy demand.

In the Netherlands buildings are being built according to the ‘Trias Energetica’ approach (also discussed in chapter 1.3) and shown in Figure 12.

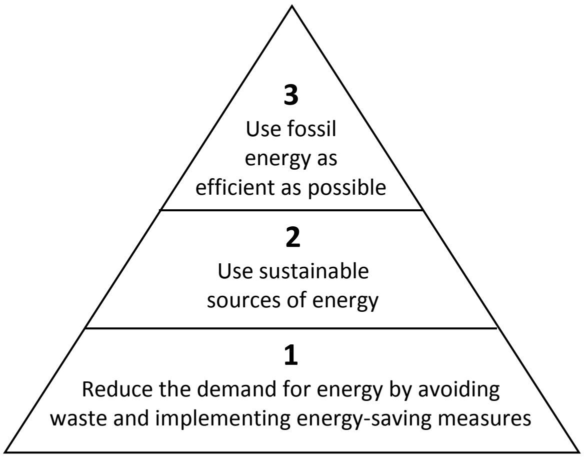


Figure 12: Trias Energetica concept.

In the future more decentralized energy production will take place and also more intermittent sustainable sources will be used. This makes the need for energy storage (electrical, heat) and local energy exchange (smart grids) more important.
The energy saving measures overview for buildings (Table 15) has been adapted to these changes by adding 2 steps: first measures improving (local) energy exchange and second storage of renewable energy.
These steps are implemented in this order because it is, from an energetically point of view, more favourable to directly utilize (renewable) energy than to store it. This is mainly because of high cost and energy losses of energy storage systems. For nZEB the last step should be avoided as much as possible, to ensure buildings only use renewable energy sources.

The adapted version of the Trias Energetica:

1. Reduce energy demand by implementing energy-saving measures.
2. Use sustainable sources of energy.
3. *Take measures that improve (local) energy exchange.*
4. *Storage of renewable energy.*
5. Use fossil energy as efficient as possible.

Table 15 shows energy saving measures for buildings in urban area, suburban area and rural area. The measures are subdivided according to the adapted version of Trias Energetica. The checkmarks indicate whether the measure is (technically, economically) suitable for the specified area.
More detailed description about technologies utilizing sustainable energy sources can be found in Appendix V, which mainly describes the technical and financial potential. The measures that are described in Appendix V are indicated with a remark in Table 15.

Two energy saving measures that have not been included in Table 15, but do show promise for the future, are the Baopt ventilation system and Earth, Wind & Fire (EWF) – Air-conditioning, presented in Appendix V [C]. The Baopt system is already being applied in several projects, but the working principle (energy savings) still has to be scientifically proven. The EWF air-conditioning is still in a research phase and its applicability and energy saving effect should be further investigated.

Table 15: Energy saving measures for building in three Urban area, Suburban area and Rural area.

Energy saving measures for buildings	Urban area	Suburban area	Rural area	Remark
1. Measures reducing primary energy demand				
• Insulation R_c = 6-8 [m^2K/W]				
• Insulation R_c = 6-8 [m^2K/W]	✓	✓	✓	
• Insulation R_c = 8-10 [m^2K/W]	*	✓	✓	*possibility of overheating
• Windows U = 1.7-1.2 [W/(m^2K)]	✓			
• Windows U = 1.2-0.7 [W/(m^2K)]	✓	✓	✓	
• Increase glass percentage	✓	✓	✓	
• Coated glazing (ZTA)	✓			
• Energy efficient lighting (8 W/m^2)	✓	✓	✓	
• Smart lighting system (daylight/presence detection)	✓			
• Mechanical ventilation (heat recovery 95%)	✓	✓	✓	
• Fixed shading	✓	✓		
• Automatic shading system	✓	✓	✓	
• Shower heat exchanger		✓	✓	
• Climate zones (rooms)	✓	✓		
• Workplace climate control	✓			
2. Technologies utilizing sustainable energy sources				
• Ground Source Heat Pump (GSHP)	✓	✓	✓	Appendix V [A]
• Aquifer Thermal Energy Storage (ATES)	✓	✓		Appendix V [A]
• Deep Geothermal systems	✓			Appendix V [A]
• Combined Heat and Power (CHP)	✓	✓		Appendix V [A]
• Solar Collector (SC)		✓	✓	Appendix V [A]
• Photovoltaic's (PVs)	✓	✓	✓	Appendix V [A]
• CHP with biomass		✓		Appendix V [B]
• Small wind turbines	✓	✓		Appendix V [B]
• Photo Voltaic Thermal systems (PVT)		✓	✓	Appendix V [B]
• Photo Voltaic Tubes	✓	✓	✓	Appendix V [B]
• ATES with Road Collector	✓	✓		Appendix V [B]
• Pellet burner		✓	✓	
3. Measures improving energy exchange				
• Rest heat	✓	✓		Appendix V [A]
• Advanced control systems for smart grids	✓	✓		Appendix V [C]
• Smart Grids for local electricity exchange	✓	✓	✓	Project 2, 4, 10, 19, 21 (Table 14)
• Smart Grids for electricity storage EV	✓	✓	✓	Project 18 (Table 14)
• Smart appliances (fridge, (dish) washer, etc)	✓	✓	✓	Project 9 (Table 14)
• Energy exchange inside buildings (zones, rooms)	✓			
• Energy exchange between building and surrounding	✓	✓		Project 8, 22 (Table 14)
4. Storage of renewable energy (electrical, thermal, chemical)				
• Phase Changing Materials (PCMs)	✓	✓		
• Batteries			✓	
• Thermal basins (heat storage)	✓	✓		
• Hot water boiler (combined with SC)		✓	✓	
• Cold storage (ice tanks)	✓			
• Cryogenic energy storage ('liquid' heat)		✓		
• Heat storage (pebbles, rock, concrete)	✓	✓		
5. Technologies using fossil fuel efficiently				
• Combined Heat and Power (CHP)	✓	✓		Appendix V [A]
• Micro Combined Heat and Power (µCHP)		✓	✓	Appendix V [B]
• High Efficiency boiler* (HR 107)		✓	✓	*also on green gas
• Electric boiler*	✓			*also on green electricity

Relevant technologies utilizing sustainable energy sources for nZEBs are extensively discussed in Appendix V. The following paragraphs will shortly discuss the GSHP and the ATES systems because they are most interesting for nZEBs in the Netherlands; full description can be found in Appendix V.

Ground Source Heat Pump

GSHP systems are closed loop systems in which ground heat exchangers are used. Two types of layouts exist: vertical systems and horizontal systems. In the Netherlands a vertical GSHP is more convenient because of limited space. Usually depths of vertical boreholes are within a range of 20 to 250 meter. Typical costs for vertical boreholes in the Netherlands are about 30 euro per meter. [91]

Figure 51 and Figure 52 in Appendix VI show the heat and cold potential from vertical heat exchangers in the Netherlands. The average annual heat extraction is over 1000 GJ/ha and cold extraction is 450 GJ/ha. Though this technology is not applied as much as in other European countries, enough experience and knowledge on closed GSHP system is present at Dutch installer companies. [105]

Costs of GSHP systems (electrical heat pump in combination with heat exchangers) vary widely and depend mainly on the capacity. In the Netherlands costs are around €14,000 to €20,000 for individual systems with a capacity of 10kW. Collective systems (with 10 to 40 dwellings) reduce costs to be around €10,000 per dwelling. [105]

Aquifer Thermal Energy Storage

In ATES systems, heat is not extracted from the ground by indirect means via a heat exchanger, but directly through extraction of the ground waters. Aquifers are natural water carrying layers in the ground that have such high permeability that the water can flow through easily. [91] In the Netherlands, a large part of the country has suitable aquifers as shown in Figure 53, Appendix VI.

A default system layout has two vertical tubes going into the ground connected to a hot well and a cold well at different horizontal locations (‘doublet’). Typically, 100 to 150 meter distance between the wells is used; this makes this system suited for buildings with a relative large lot.

Another design is for an aquifer system is a recirculation system; this is a more simple design in which only one well is used for extraction and the other for injection. The temperature of the well is more or less fixed on a temperature of 10°C because hot water is injected in the summer and cold water in the winter.

In the Netherlands aquifer systems usually have a depth between 20 and 200 meters. Aquifer systems are suitable for large offices, residential areas (30 to 50 dwellings) and industrial areas. ATES technology is a mature technique that is applicable (profitable) without any subsidies. The current payback period of aquifers systems of office buildings is between 3 and 7 years. Presently in the residential sector, heating is the primary need, while cooling demand is low (almost now existing); therefore ATES is not interesting. However, it is expected that heating demand will decrease (and cooling demand increase), because newly built houses will be insulated better and have better air tightening. This makes aquifers systems a very interesting option for nZEBs. [107]

4 Scenarios for nZEBs

This chapter presents three nZEB scenarios for different areas. A reference building is determined for every area, which is also used in the cost-optimality calculation in chapter 5. First the building density in the Netherlands is determined to get a good overview on the different areas. The following areas with corresponding reference buildings will be explored:

Ch. 4.2	Urban area	→	Office building
Ch. 4.3	Suburban area	→	Terraced house
Ch. 4.4	Rural area	→	Detached house

Every subchapter begins by describing the reference building (size, geometry, etc.). Then the infrastructure scenarios are sketched to gain insight on changing conditions. Innovative technology and smart grid introduce a new type of decentralized infrastructure which has effect on infrastructure on all levels (national, regional and local).
At the end of each subchapter building technology scenario describes four scenarios per area:

- *Reference scenario*; these scenarios have an EPC according to the coming regulation (2015) for the specific building function as shown in Table 3. The construction properties and installations have to apply to the building regulations and are specified according to the Agency NL reference buildings. [41][47][77]
- *nZEB scenarios*; three nZEB scenarios per area will be determined with an EPC ≈ 0. The construction properties are based on Agency NL nZEB reference buildings [43][78] and examples of nZEBs described in chapter 2.2 and 2.3. Installations have been determined using energy saving measures Table 15 (chapter 3.2).

The calculation tool ENORM (from dGmR) [71] has been applied to determine the EPC and primary energy demand of the reference buildings (U_{ref}, S_{ref}, R_{ref}) and nZEB scenarios for all areas (U_{1-3}, S_{1-3}, R_{1-3}). This tool allows comparing buildings with different geometries, construction aspects, installations (heating, cooling, hot tap water, ventilation, and humidification), solar energy and lighting. Calculation methods within ENROM are based on NEN 7120 for energy performance of building.

The ventilation rate and the internal heat gains have great influence on building performance. Ventilation rates of the reference buildings used by Agency NL have been applied in the ENORM calculation. It was noted that the ventilation rate for dwellings (terraced house and detached house) was not higher for the nZEB buildings; this was expected since additional ventilation leads to a better indoor climate, as described in chapter 5.3.1.
Internal gains in office buildings plays a major role in office buildings, especially in well insulated (nZEB) buildings where overheating can occur. In a study on future trend in office internal gains (including occupants, equipment and lighting) and the impact of space heating and cooling, three scenarios where analysed. [72] Two of these scenarios were interesting for this study: a benchmark scenario with an internal gain of 80kWh/m²a an energy conscious ICT scenario predicting internal gains of 35kWh/m²a. These were used in simple CASAnova simulation too see the effect on the office building. Significant effects were found, however values from this study could not be used in ENORM since the calculation method uses a completely different method, described in NEN 7120 (H10). Therefor standard internal heat gain values, from ENORM (NEN 7120), were used in the EPC calculation.

4.1 Building density

The Netherlands has a high population density and is one of Europe's most populated countries. This has large consequences for the use of land area. In the Netherlands the four largest cities (Amsterdam, Rotterdam, Den Haag and Utrecht) can be found in the western provinces, and they form a 'horseshoe' like shape called the Randstad. The area in between the 'horseshoe' is called the Green Hart with relatively large open spaces. Almost 40% of the Dutch population lives in the Randstad. Agglomerations in the Netherlands usually have a population between 100,000 to 5000,000 inhabitants. The Randstad is also seen as a dispersed metropolitan area; this leads to traffic congestions and locally higher concentration of particular matter compared to the rest of the Netherlands. In the southern and eastern provinces urban regions are formed. [73]

Figure 13 shows the housing density (number of houses per acres of land) of all Dutch municipalities per percentage of the entire Dutch population. The housing density is obtained by dividing the municipality land area by the number of dwellings ('housing stock'). Surface water (lakes, rivers, channel, etc.) is excluded from the land area when it has a width of 6 meters or larger. All other infrastructure (roads, railways, etc.) and other type of buildings are not incorporated in these numbers. In reality housing density is higher than shown in these figures. A typical residential district in urban area counts about 60 dwellings per acres. Suburban districts usually count about 30 dwellings per acres.
The total population of the Netherlands is 16.7 million inhabitants (January 2011), which means that almost three quarter of the population lives in a municipality with relative small housing density (0-10 houses density per acres of land).

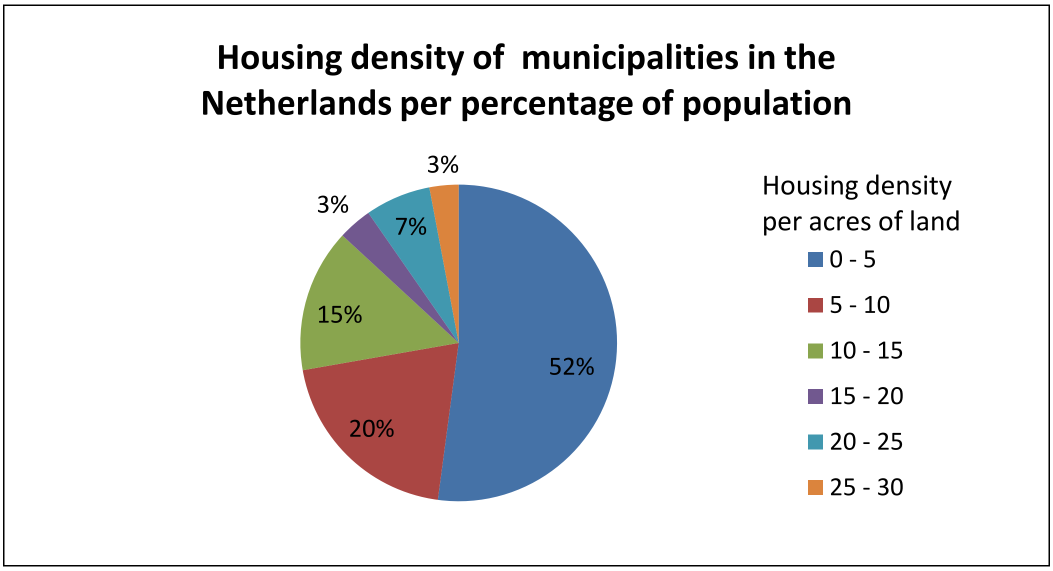


Figure 13: Housing density of municipalities in the Netherlands per percentage of population. [74]

Figure 14 presents the urbanisation of municipalities in the Netherlands per percentage of population. This figure shows the address area density: the number of addresses per square kilometre, which is categorized as followed:

- 2500 addresses or more per km^2 → Highly urbanized municipalities
- 1500 to 2500 addresses per km^2 → Strongly urbanized municipalities
- 1000 to 1500 addresses per km^2 → Moderate urban municipality
- 500 to 1000 addresses per km^2 → Little urban municipality
- less than 500 addresses per km^2 → Rural area municipality

From Figure 14 can be concluded that 48% of the Dutch population lives in highly and strongly urbanized municipalities. It is important to focus on these populated areas, since these municipalities have less space and therefor limited possibilities for renewable energy generation. High urbanization density also leads to opportunities; due to higher prices of land relatively expensive techniques can become more feasibly than large scale (area) systems.

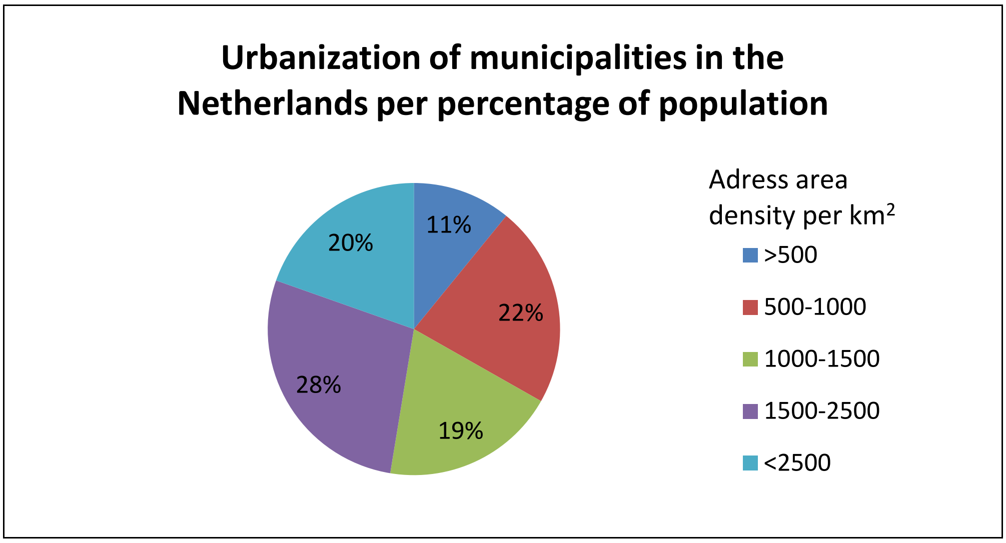


Figure 14: Urbanization of municipalities in the Netherlands per percentage of population. [74]

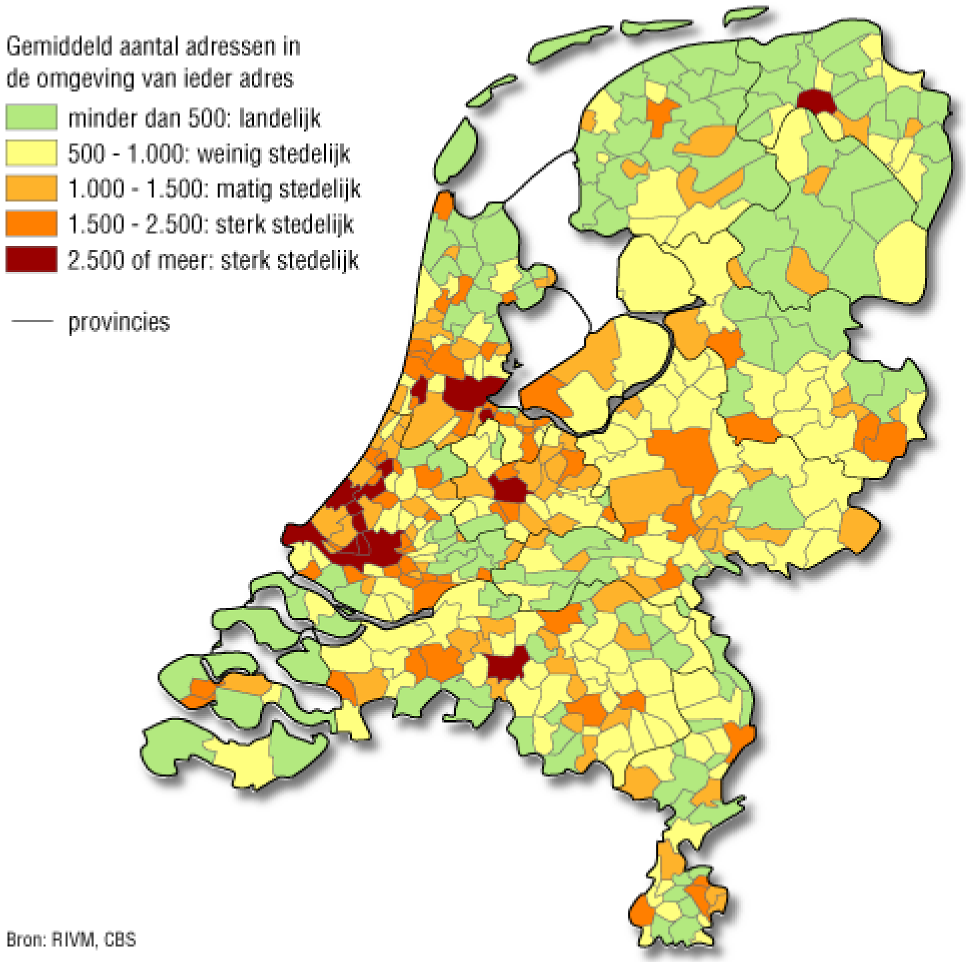


Figure 15: Address area density per municipality in the Netherlands (2009). [75]

4.2 Urban area

The Netherlands consists of many urban areas and regions such as the Randstad. Urban area is represented by cities high population density. Since the population density of offices is generally higher than for apartment blocks or flats (higher population per floor space), an office building will be used as reference building.
The reference office building that will be used (from Agency NL) is a middle size office with a user surface of approximately 3000 m^2. The building has rectangle geometry with a four floors. Dimensions of the reference building are given in Table 16.

Table 16: Properties of office reference building. [47]

	Reference building	Actual values used	
Height Floor height	14.4 3.6	14.4 3.6	m m
Length	56.7	50.0	m
Width	14.4	15.0	m
User surface, A_g	3266	3000	m^2
Heat loss surface, A_{loss}	2864	2622	m^2
Ratio A_g/A_{loss}	1.14	1.14	-
Window percentage	35	35	%

4.2.1 Infrastructure

Figure 17 and Figure 16 show infrastructures of an urban area for a current situation and future scenario. These specific infrastructures have been adapted to the conditions of the city of Rotterdam. Information on current and future energy infrastructure plans in Rotterdam can be found in Appendix VII.

In the current situation (Figure 17) all buildings are connected to the electricity grid, mainly powered by gas fired power plants. A small part of the electrical energy is generated by of by wind energy and CHP power plants. [76]
In the Netherlands most buildings have a gas connection, however in Rotterdam heat and steam networks are also widely used in the urban area. Industrial complexes in the port of Rotterdam produce heat and CO_2 which is used for heating of building and greenhouses. Most residential and office buildings are equipped with central heating systems using a high efficiency boiler. Modern offices use balanced ventilation with heat recovery which reduces heating loads considerably.

In the future scenario (Figure 16), solar energy will be used more frequently. Many new and existing buildings will be equipped with PV cells. Existing building roof tops will be covered, however in new buildings Solar Collectors (SC) and PV panels will be integrated.
It is expected that heating networks will be extended and used mainly for residential district heating. Large apartment buildings and offices will more often use innovative technologies for heating and cooling. Heat networks between buildings are a possibility: office buildings providing heat to dwellings or apartments.
Well insulated building in the future will have a higher cooling demand. Solutions for these increasing could be found using the cooling capacity of the earth. Rotterdam has good potential for aquifer systems because the city is situated in an area with high potential, as can be seen in Figure 53 (Appendix VI). Also GSHP and deep geothermal systems have good technical potential (Figure 51, Figure 52 Figure 54 and Figure 56 in Appendix VI). In addition to the normal GSHP a road collector can be used to further optimise this system.
Innovative systems that can be used on building level are small scale wind turbines.

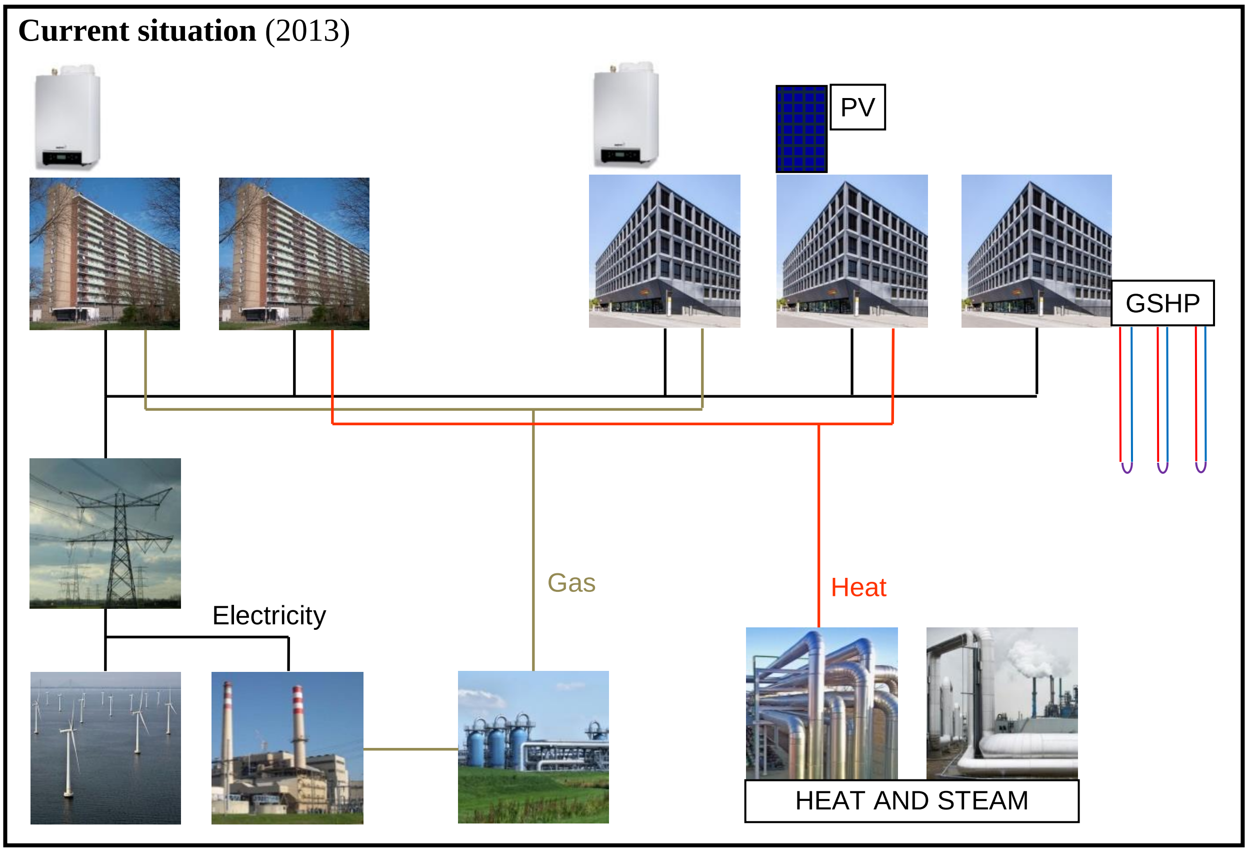


Figure 17: Urban area infrastructure for current situation.

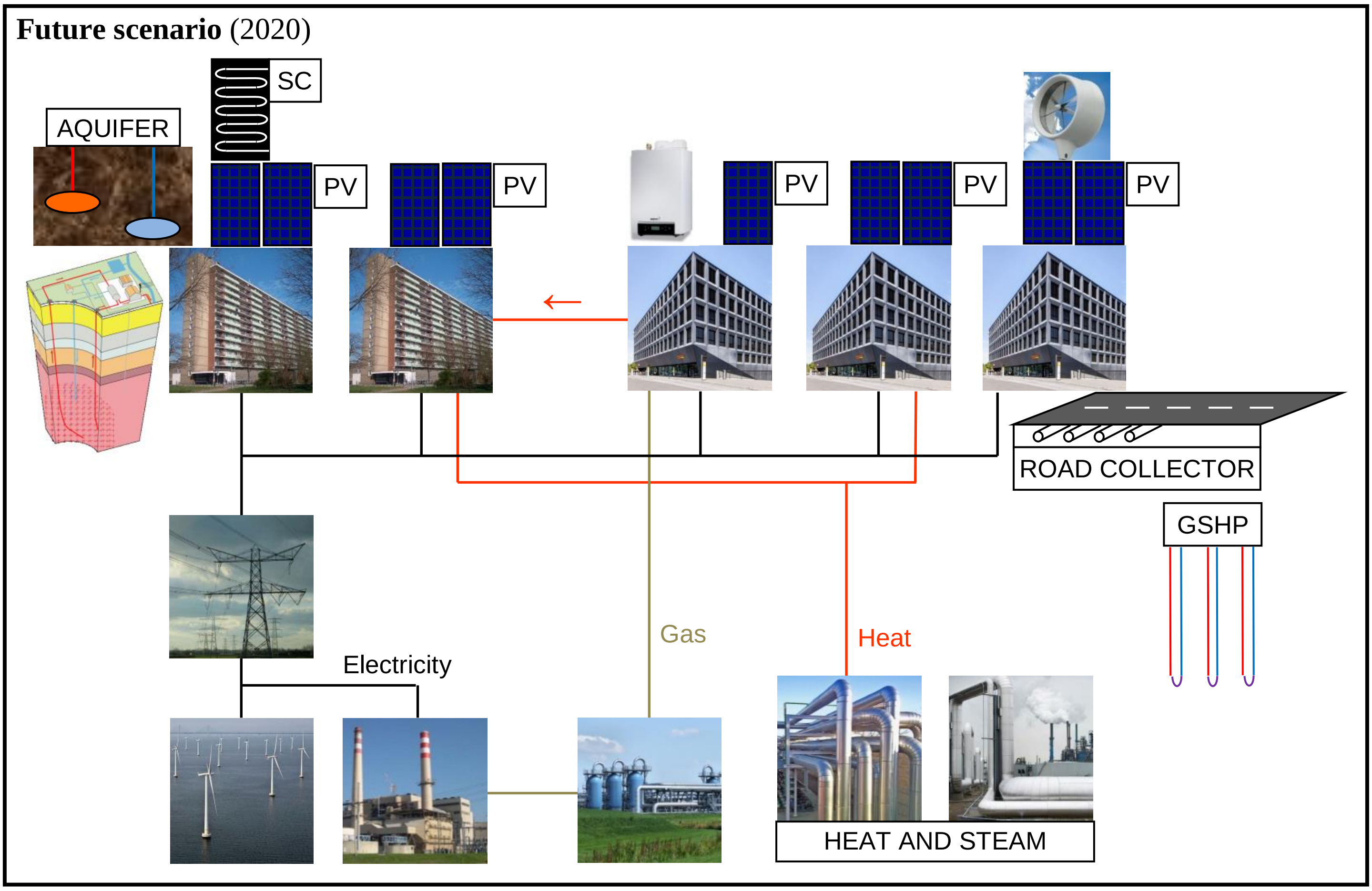


Figure 16: Urban area infrastructure for future scenario.

4.2.2 Building technology scenarios

Four building designs for the urban area are discussed: one reference building and three nZEB scenarios with energy saving measures. The focus will be on building installations, mainly the differences between the technologies. A complete overview on building specifications and energy performance can be found in Appendix VIII.

A brief overview on the different building installation is shown in Table 17. The main difference between U_{ref} and the nZEB scenarios (U_1, U_2, U_3) is the application of PV cells: about seven times larger surface is applied in the nZEB scenarios. Applying panels on the roof was not sufficient enough to lower the EPC, so PV cells had to be installed on the facade. In Appendix VIII an explanation is given about the different PV façade design options. The highest yield was obtained by placing the panels at a sloped angle.

Heating and cooling is provided with GSHP and ATES systems, also discussed in chapter 3.2. An innovative system called the road collector was applied in U_3 which allows to better balance the ATES system resulting in better performance. More information on the road collector can be found in Appendix IV [B].

All office building concepts (U_{ref}, U_1, U_2, U_3) have an mechanical balanced ventilation system with heat recovery. The heat recovery efficiency differs between the reference building and the nZEB scenarios.
Smart lighting systems with high frequency lighting of 8 W/m^2 are utilized in all scenarios. The system controls light intensity with day lighting sensor and switches on and of using presence detection sensors.

Table 17: Building installations for urban area scenarios. [47]

	Urban Area scenarios Office building			
	U_{ref}	U_1	U_2	U_3
EPC	0.70	0.20	0.14	0.15
Primary energy demand [kWh/(m²a)]	79.0	23.1	15.4	17.1
Installations				
Heating / Cooling	Vertical GSHP with low temperature (30-35°C) floor heating	Vertical GSHP with low temperature (30-35°C) floor heating	ATES with low temperature (30-35°C) floor heating	ATES with Road Collector with low temperature (30-35°C) floor heating
Hot tap water	Small electric boiler	Small electric boiler	Small electric boiler	Small electric boiler
Ventilation	Mechanical (balanced) with heat recovery (70%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)
Lighting system	Efficient lighting system (8 w/m^2)	Efficient lighting system (8 w/m^2)	Efficient lighting system (8 w/m^2)	Efficient lighting system (8 w/m^2)
Electricity generation	PV cells 170 m^2 (roof)	PV cells 770 m^2 (roof) 375 m^2 (façade)	PV cells 770 m^2 (roof) 375 m^2 (façade)	PV cells 770 m^2 (roof) 375 m^2 (façade)

4.3 Suburban area

A suburban area of a city or town is usually a residential district at the outskirts of the city. In the Netherlands these neighbourhood are relatively new compared to the old centre. Residential districts generally have more green space and parks and have a typical density of 30 dwellings per acres. These residential districts usually consist of single-family houses, but can also be an area with flats or apartment buildings.

A residential district with terraced houses will be used as reference building for the suburban area. In the Netherlands approximately 50% of all newly built buildings are terraced houses. The reference buildings (corner and middle terraced houses) will be used (from Agency NL) with a user surface of 124 m^2. The properties and dimensions of the terraced reference house are shown in Table 18. The size of the urban area is assumed to be a total of approximately 1000 residences. Additional information can be found in Appendix III.

Table 18: Properties of terraced house referenc buildings. [40]

Height Floor height	10.2 2.6	m m	
Length	8.9	m	
Width	5.1	m	
User surface, A_g	124.3	m^2	
Heat loss surface, A_{loss}	156.9 230.0	m^2 m^2	Middle house Corner house
Ratio A_g/A_{loss}	0.8 0.5	- -	Middle house Corner house

4.3.1 Infrastructure

Figure 18 and Figure 19 show infrastructure of a suburban area for a current situation and future scenario. A residential area with terraced houses is used as reference buildings.

In the current situation (Figure 18) all houses in a residential district are connected to the electricity grid. Electricity is mainly produced by gas fired power plants and a small amount is provided by wind energy.
All houses in the suburban area are connected to the gas infrastructure and heated by high efficiency boilers. Some houses already us renewable energy sources, such as PV cells, solar collectors or vertical GSHP, however these systems often are retrofitted.

In the future scenario (Figure 19), smart grids will be used more frequently on district level. All houses are connected to each other and will have the ability to directly exchange electricity. Another important feature of suburban districts will be PV, SC and small wind turbine systems implemented in roofs and facades. Electrical Vehicles (EV) and smart appliances (washing machine, fridges) will be used more frequently and integrated in the local smart grid. Smart meters in every home (within the district) will able communication with other buildings, controlling supply and demand on district level.
For the future scenario it is expected that heating and cooling systems for districts will be combined, since heating and cooling load per house will be reduced by good insulation, air tightness and ventilation systems with heat recovery. It is expected that cost of combined heating/cooling systems are lower than individual systems. Innovative techniques that can be used on district level in the urban area are: (rest) heat network, GSHP system, ATES system or a biogas plant. The technical ability and cost effectiveness of these techniques is mainly dependent on the location.

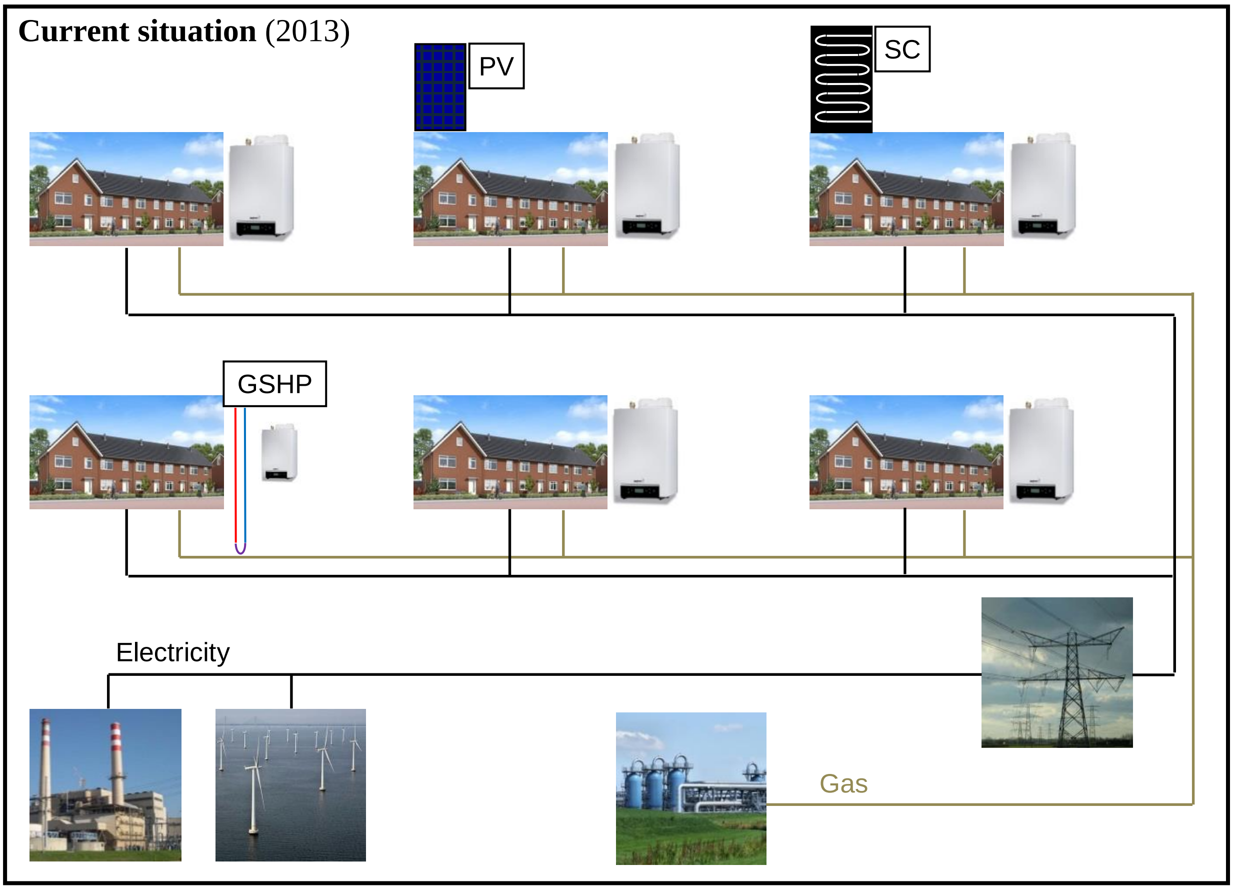


Figure 18: Suburban area infrastructure for current situation.

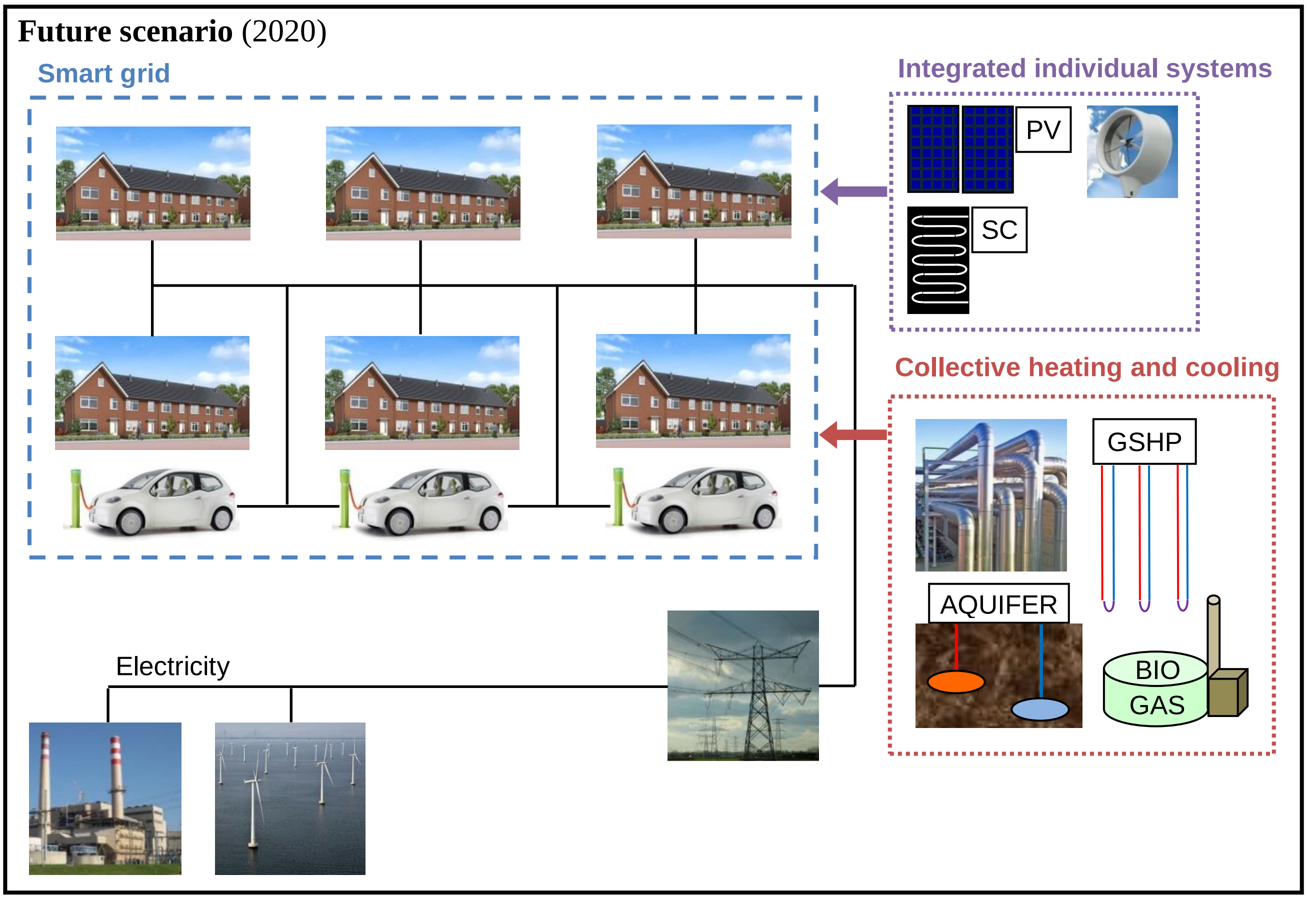


Figure 19: Suburban area infrastructure for future scenario.

4.3.2 Building technology scenarios

Four building designs for the suburban area are discussed: one reference building and three nZEB scenarios with energy saving measures. The focus in this section will be on building installations, mainly the differences between the technologies.

The building installations for the reference building (S_{ref}) and the nZEB scenarios (S_1, S_2, S_3) are shown in Table 19. Due to time constrains no cost optimality calculations are performed, and no further information on the suburban area scenarios will be given.

Table 19: Building installations for suburban area scenarios. [43]

	Suburban Area scenarios Terraced house			
	S_{ref}	S_1	S_2	S_3
EPC	0.4	≈ 0	≈ 0	≈ 0
Installations				
Heating	High efficiency gas boiler (107HR)	Vertical GSHP with low temperature (30-35°C) floor heating	Air-to-air heat pump with air heating/cooling via ventilation	Combined ATES with low temperature (30-35°C) floor heating
Cooling	No cooling			
Hot tap water	Solar collector	Solar collector	Solar collector	Solar collector
Ventilation	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)
Electricity generation	-	PV cells ($25m^2$)	PV cells ($25m^2$)	PV cells ($25m^2$)

4.4 Rural area

In rural area prices of land are considerable cheaper than in urban and suburban area; therefore (semi-)detached houses are built more in these regions. From Figure 14 and Figure 15 can be seen that rural area is defined as an address area density smaller than 500 per square kilometre. The green municipalities in Figure 15 shows rural areas are located mainly in the north, east and south-west of the Netherlands.

Detached and semi-detached houses represent approximately 5% and 13% of all newly built buildings in the Netherlands. Detached houses usually consist of three bedrooms and are often fitted with a saddle roof. [40]
A detached house with a user surface of 170 m^2 will be used as referential building (Appendix III). Since semi-detached houses (‘two-under-one roof’) have a smaller heat loss surface, it is assumed that building measures (constructive and installation) for detached houses also satisfy for semi-detached houses. The average surface plot for the reference building is calculated to be 2000 m^2, which complies with the address density of 500 buildings per m^2.

Table 20: Properties of detached house and semi-detached house referenc buildings. [40]

	Detached house	Semi-detached house	
Height Floor height	10.2 3.0	10.6 2.9	m m
Length	10.2	9.0	m
Width	2.6	2.6	m
User surface, A_g	169.5	147.7	m^2
Heat loss surface, A_{loss}	358.4	268.5	m^2
Ratio (A_g/A_{loss})	0.5	0.6	-

4.4.1 Infrastructure

Figure 20 and Figure 21 show infrastructure of a rural area for a current situation and future scenario. For the rural area a detached house is taken as reference building.

In the current situation (Figure 20) detached houses are connected to the electricity grid. Electricity generation by PV panels occurs on small scale in the Netherlands, usually with retrofitted panels. All electricity that is not consumed directly is fed back into the grid.
In rural areas gas infrastructure is usually not present and many detached residential buildings use a gas tank. Heating and hot tap water is provided by a high efficiency boiler combined with a central heating system. Additional systems regularly applied for heating and hot tap water are solar collectors and horizontal GSHP.

In the future scenario (Figure 21) detached houses will be still attached to the electricity grid. The main difference in current situation will be the integrated energy systems such as PV panels, a solar collector and small wind turbines. When roof space is limited or a flat roof is present, PVT panels can be a solution to provide enough thermal and electrical energy.
Heating and cooling of the dwelling is mainly provided by horizontal GSHP. The large building plot allows application of a horizontal GSHP, which is an advantage compared to the more expansive vertical GSHP.
An electric car will also be part of the energy systems in the detached house. The annual energy demand of the EV will not be provided by the on-site electricity production; however the EV can serve as a storage system in the summer when PV panels produce an overcapacity. At times when PV electricity supply is lower, sustainable electricity from the grid (wind energy, hydropower) have to be used.

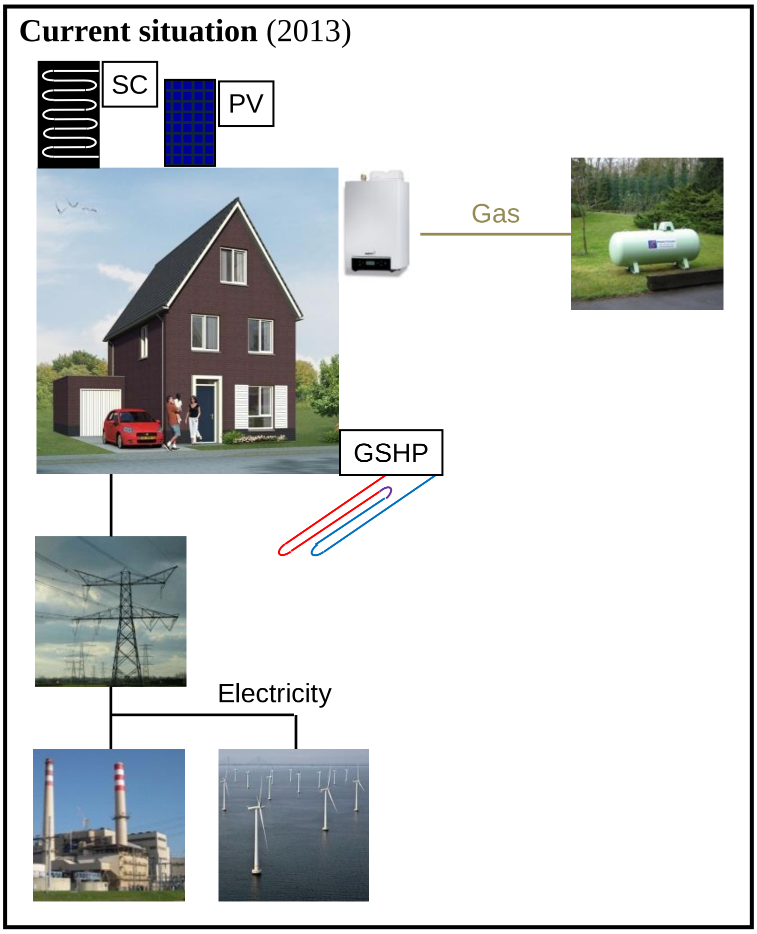


Figure 20: Rural area infrastructure for current situation.

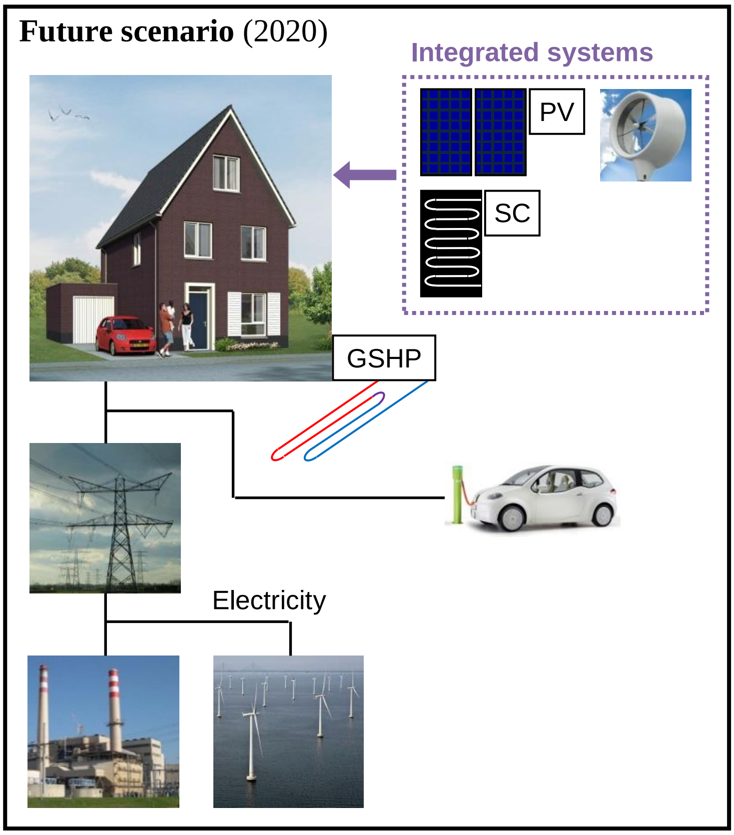


Figure 21: Rural area infrastructure for future scenario.

4.4.2 Building technology scenarios

Four building designs for the rural area are discussed: one reference building and three nZEB scenarios with energy saving measures. The focus in this section will be on building installations, mainly the differences between the technologies.

The building installations for the reference building (R_{ref}) and the nZEB scenarios (R_1, R_2, R_3) are shown in Table 21. Due to time constrains no cost optimality calculations are performed, and no further information on the suburban area scenarios will be given.

Table 21: Building installations for rural area scenarios. [78]

	Rural Area scenarios Terraced house			
	R_{ref}	R_1	R_2	R_3
EPC	0.4	≈ 0	≈ 0	≈ 0
Installations				
Heating	High efficiency gas boiler (107HR)	Vertical GSHP with low temperature (30-35°C) floor heating	Air-to-air heat pump with air heating/cooling via ventilation	Combined ATES with low temperature (30-35°C) floor heating
Cooling	No cooling			
Hot tap water	Solar collector	Solar collector	Solar collector	Solar collector
Ventilation	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)
Electricity generation	-	PV cells ($25m^2$)	PV cells ($25m^2$)	PV cells ($25m^2$)

5 Cost optimality

In this chapter cost-optimality calculations will be executed to determine if the nZEB scenarios (Ch. 4) are within the cost optimal range and how additional gains can further reduce LCC. Due to time constrains, LCC calculations have only been performed for the urban area with the office reference building.

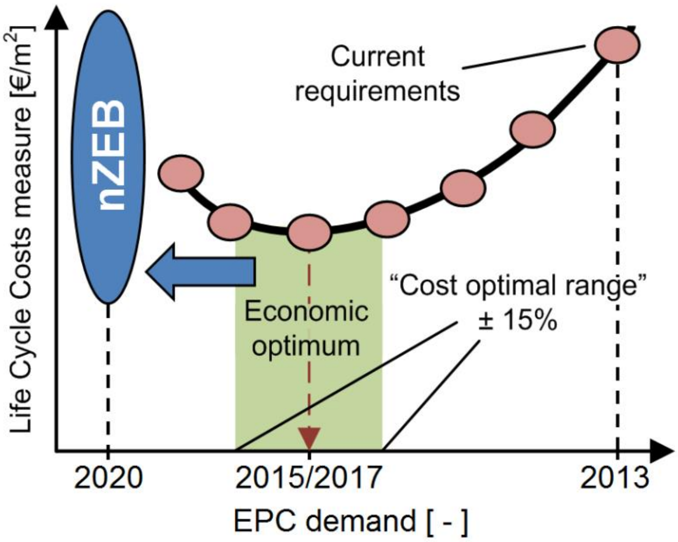


Figure 22: Life Cycle Costs versus EPC demand.

Figure 22 shows the LCC versus EPC demand, which is closely related to the primary energy demand. This chapter will start off by describing the background of cost-optimality calculation studies in the Netherlands. Next principles of the LCC calculation are explained together with the method. Two analyses will be conducted: a financial analysis and a macro-economic analysis. Also a sensitivity analysis is executed and shortly discussed.
One paragraph will be dedicated to the additional gains: scientific research is discussed and applied in the LCC calculation. Since calculations are only executed for office buildings, focus will be on improved productivity by and enhanced climate and reduced sick leave due to improved ventilation.
At the end of the chapter results of the cost optimality for office buildings are shown. Resulting graphs show LCCs over 30 years versus the EPC demand and the primary energy.

5.1 Background

The cost-optimality is a crucial aspect for the introduction of nZEBs in the Netherlands. Since 1995 cost-optimality calculations have been the foundation of governmental policies on energy savings within the building sector. Earlier studies by dGmR and RHDHV have investigated the cost effectiveness of energy reducing measures for newly built residential and utility buildings. Appendix IX shows the underlying documents which provide the foundation for this study. Summaries on previous (underlying) studies are presented in following paragraphs.

In 2009 dGmR studied the effects on lowering the EPC to 0.6 for residential buildings in 2011. [79] The goal was to gain insight about the effect of EPC reduction on the indoor environment, energy demand, CO_2 emissions, the relation between investment costs and energy saving measures. A practical method was applied, to determine energy saving measures for the theoretical part. It was concluded that for all investigated residential building types an EPC of 0.6 was feasible.

In 2013 a following study was performed by dGmR, on cost optimality of energy saving measures for residential and utility building according to the EU calculation method. [80] Financial and macro-economic calculations were performed to determine the cost optimality of existing and newly built buildings, using discount rates, interest rates and energy price scenarios prescribed by the European Commission.
The results for the financial and macro-economic calculation were quite similar, so only the results for financial cost optimality analysis will be shortly discussed. The following graphs show the additional net constant costs for different packages (energy saving measures) compared to the EPC (Q/Q) demand of different building types/functions. To satisfy the EPC demand (from the 2013), it is important that proposed measures result in a Q/Q below 1.00.

Figure 23 and Figure 24 show the additional Net Constant Costs (NCC) for energy saving measures for residential buildings and office buildings, respectively.
For residential building it can be seen that the majority of the energy saving measures lies within around 1.00, suggesting these measures satisfy the EPC demand of 0.6. The additional NCCs are about €50 to €150 per square meter for most energy saving packages.
Almost all measure for office building satisfy the EPC demand and cost of energy saving measures prove to be cost neutral or even cost reducing! This means that all applied measures are already cost effective for an EPC of 1.1.

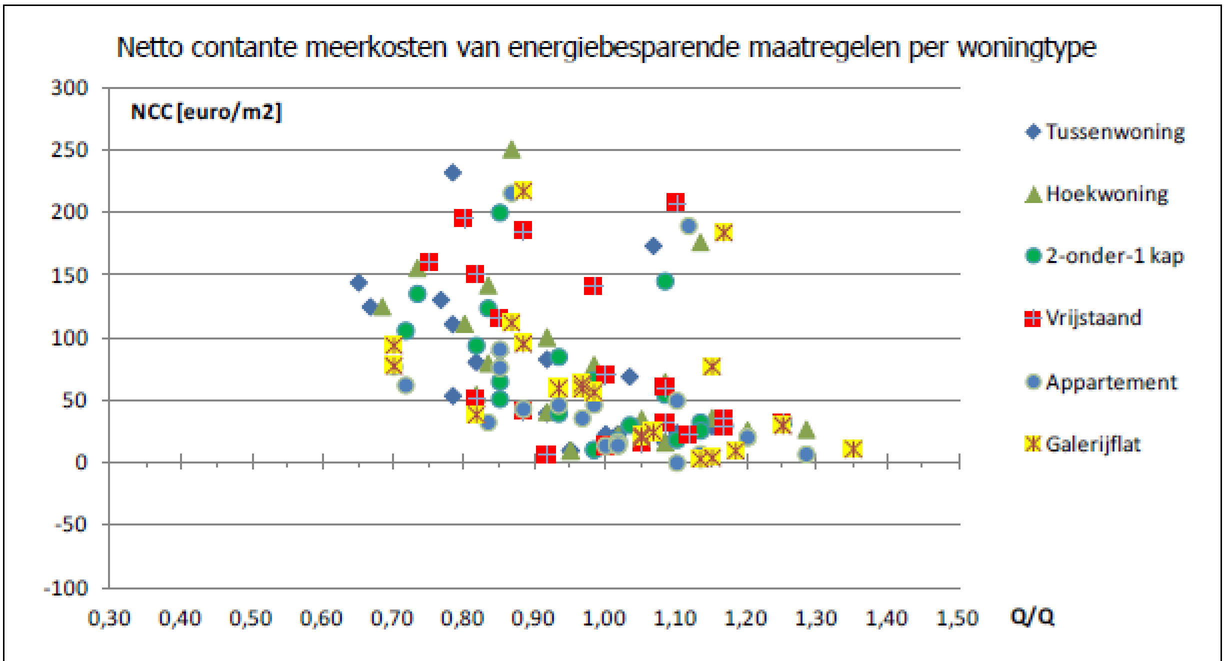


Figure 23: The additional net constant costs of energy saving measures for residential buildings. [80]

The reference buildings used in the dGmR study are from Agency NL and are the similar size as the office building (kantoor middel), terraced house (tussenwoning) and the detached house (vrijstaand) in this current study.
The results of the dGmR study [80] have been reproduced to compare the calculation method of this study, see Appendix X. Similar results were found, comparing the three best energy saving measures for a middle sized office building with a reference building.

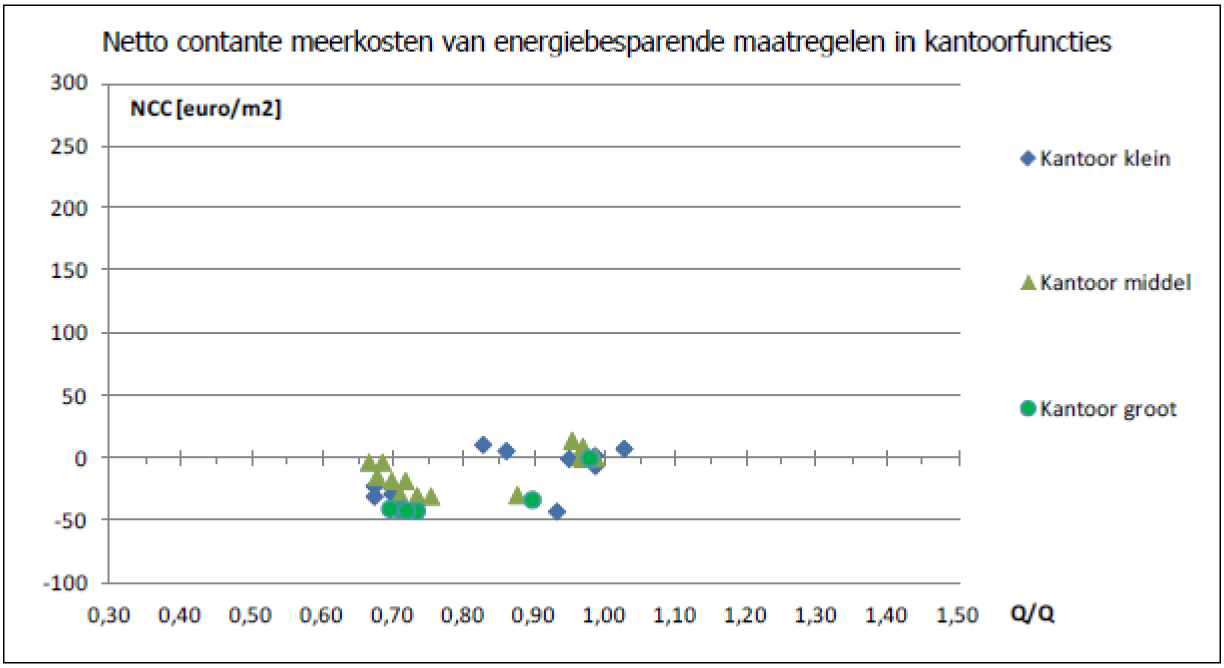


Figure 24: The additional net constant costs of energy saving measures for office buildings. [80]

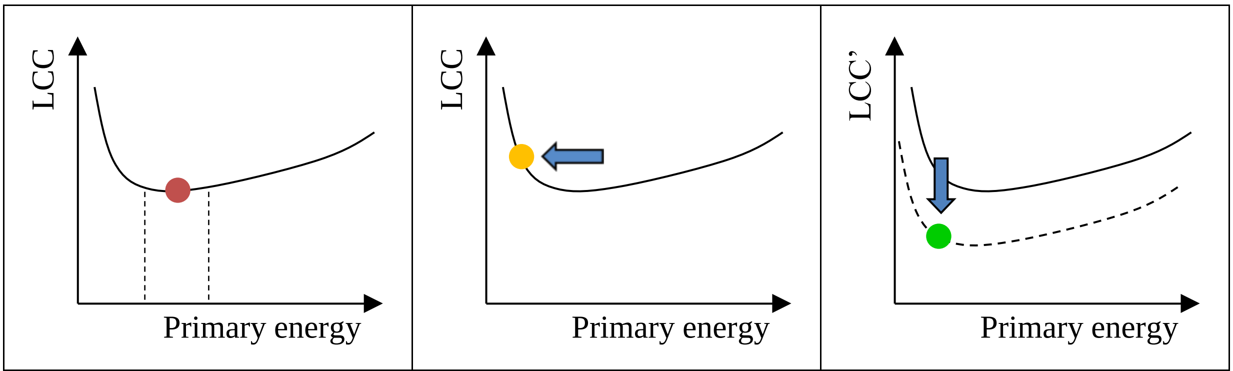
In 2013, during the same period of the dGmR study, a research was performed by RHDHV on the proposed tightening of the EPC demand of 0.6 to 0.4 for residential buildings. [81] The tightening EPC demands require a new improved cost effectiveness methodology, therefore a practical and theoretical test have been developed for both residential and utility buildings. Focus point in this new methodology were to create a clear method for all building types, to adapt the existing method to new EU demands, and to include additional gains into the LCC calculation.

The RHDHV study lies at the base of the cost optimality calculation performed in this report. Information used from this report will be discussed later on. In addition to the RHDHV study, updates made by an RHDHV employee on the interest rate and discount rates are also taken into account. [82]

5.2 Method

This section describes the modifications to the standard cost optimality calculation. Further the methodology is explained: first discussing the principles, than the financial and macro-economic analyses, and finally the sensitivity analysis.

The goal of this study is to provide nZEB scenarios with low EPC scores and primary energy consumption in combination with low LCC. Currently cost optimality calculation can be made for existing technologies (Figure 25.a). These buildings are conform to current EPC demand, and are within the cost optimal range. Buildings that have to comply with future EPC regulation will have to be equipped with future technology. This will result in low primary energy demand (low EPC), however these technologies are not cost effective yet (Figure 25.b). In order to reduce LCCs, additional gains such as resale value, productivity, etc. will be added to providing a new type of graph (Figure 25.c) in which lower LCC and primary energy are accomplished. This new calculation method is called the LCC' since it is not exactly the same method as prescribed by the EU.



Buildings with existing technologies within the “cost optimal” range	Buildings with innovative technology which are not cost effective yet	nZEBs with innovative technology which are cost effective due to new calculation method

Figure 25: Cost-optimality trajectory a) ‘standard’ scenarios b) scenario with innovative technologies c) scenario with innovative technology and new LCC’ calculation method.

5.2.1 Principles

The LCC’ cost optimality calculations have been executed using the DUBO (Duurzaam Bouwen) versneller; a LCC calculation tool developed at RHDHV [83]. The overall tool structure is explained below, and the complete input schemes for the urban area reference building and nZEB scenarios can be found in Appendix XI.

The DUBO versneller tool can be utilized to compare LCC’s of four building concept to each other. The input of the DUBO takes 4 main expenses into account:

- **CAPEX** (Capital Expanses) in [€/m²]
  - Building costs
  - Land costs
  - Installations: mechanical and electrical installations.
  - Building creators: architect, installation advisors, building manager.
- **Energy** in [€/(m²a)]
  - Electricity
- **OPEX** (Operational Expanses) in [€/(m²a)]
  - Maintenance: building, mechanical and electrical installations
  - Other building service: cleaning
  - Taxes, insurance
- **End value** in [€/m²]
  - Residual value: building, land, installations
  - Dismounting and disposal

A complete overview of the LCC’ calculation input can be found in Appendix XI. Input parameters that are of importance and may vary in the future are shown in Table 22.

Table 22: LCC’ calculation parameters. [81][82]

Inflation rate	2.3%
Discount rate	2.0%
CO_2 emission costs (averaged over 30 years)	€42.50
Energy price increase (gas, electricity)	2.8%
Financing interest	2.3%

Dynamical input costs, including replacement of installation after x number of years, have also been integrated in LCC' calculation. This allows taking refurbishments and overhauling costs into account.

For the cost optimality calculation the discounted cash flow was used. The LCC' calculation method also provides a possibility to perform a sensitivity analysis for all variable parameters such as interest rate, discount rates and energy prices. This analysis will be discussed in chapter 5.2.2.
The LCC's are determined according to the framework describe in the EPBD recast, which prescribe calculations on two levels [81]:

- *Micro economic analysis*: is also called financial analysis. The financial analysis shows financial limitation for energy saving measures to the potential investors. They can give a good view on energy measures that are not cost effective yet for the investors, but measures that are desired by the society.
- *Macro-economic analysis*: the goal of macro-economic analysis level is to prepare and inform about minimum building energy performance demands for specific building types. The analysis also contains a broader public perspective were investments in energy saving measures and related costs /gains are tested assessed with policy alternatives.

The main differences between the two methods are shown Table 23.

Table 23: Difference between financial and macro-economic analysis. [81]

	Financial	**Macro-economic**
Level	Project specific	National
CO_2 emission	✓	✗
VAT	✗	✓
Subsidies	✗	✗
Discount rage	low	middle - high
Energy tariffs	Excl. energy taxis	Incl. Energy taxis
Taxation charges	✗	✓
Discount rate - Residential buildings - Utility buildings	 5.5% 8.0%	 3.0% 3.0%

The discount rates for both the micro and macro-economic analysis have been updated in April 2013 [82]. The following values, for utility buildings, have been used in the LCC' calculation.

Discount rates:

- Financial analysis: 6.4%
- Macro-economic analysis: 2.0%

Energy prices used (Table 24) in the LCC' calculation have been determined using energy prices from three large energy suppliers for a middle sized office building. The energy demand in the cost optimality is expressed in primary energy a units, meaning primary energy has to be converted to cubic meter gas and kWh electricity. The following conversion values have been used [81]:

- Natural gas: 35.17MJ primary energy per m^3 natural gas.
- Electricity: 9.23MJ primary energy per kWh.

The electricity prices for utility buildings are distinguished for an annual consumption of <10,000 kWh, <50,000 kWh and >50,000 kWh. These tariffs can affect the energy consumption when it is close to the set limit, and it will most certainly influence the PBP of PV panels.

Table 24: Electricity prices including and excluding VAT and Energy Taxes for office buildings. [84]

	Electricity price [€/kWh]					
	Consumption <10000 kWh		*Consumption <50000 kWh*		*Consumption >50000 kWh*	
	Excluding VAT and Energy tax	*Including* VAT and Energy tax	*Excluding* VAT and Energy tax	*Including* VAT and Energy tax	*Excluding* VAT and Energy tax	*Including* VAT and Energy tax
NL Energie	0.055	0.213	0.055	0.141	0.055	0.114
Nuon	0.063	0.222	0.063	0.150	0.063	0.124
Essent	0.065	0.225	0.062	0.149	0.059	0.119
Average	**0.061**	**0.220**	**0.060**	**0.146**	**0.059**	**0.119**

The energy prices have great influence on the financial feasibility of energy saving measures. Appendix X (*Energy price course*) discusses the energy prices course of the past decade and energy price scenarios up to 2040. Energy prices are hard to predict, especially with instable positions of oil and gas producing countries, and discovery of scale gas.

The EPC and primary energy demand (determined with ENORM) have been combined with LCC' calculation to create a cost optimality graph. The results of the cost optimality will be displayed in LCC' versus EPC in chapter 5.4 and LCC' versus primary energy demand in Appendix XII.

5.2.2 Sensitivity analysis

Critical parameters of the LCC' calculation, often calculated or assumed, will be tested using the sensitivity analysis. The analysis will have to satisfy minimum requirements according to the EPBD recast for different price scenarios for energy carriers (gas and electricity) and minimal two discount rates for the micro and macro-economic analyses. The parameters may only be changed one at the time to see the changing effects. Values from [81] were adapted according to the recalculated values of [82]. The following values were used:

Discount rates (R):

- Financial analysis: 4.9% and 7.9%
- Macro-economic analysis: 1.0% and 3.0%

Energy prices scenarios:

- Financial analysis: price development of -20% and +20%
- Macro-economic analysis: price development of -20% and +20%

5.3 Additional gains

Additional gains are an important instrument to reduce ‘standard’ LCCs of office buildings. The goal of applying gains to nZEB scenarios is to ‘move’ these concepts downwards (Figure 25.c). The additional gains that will be treated are limited to improved productivity and reduced sick leave. Scientific theories on these topics are discussed and implementation of the additional gains in the LCC’ calculation is explained in following sections.

5.3.1 Scientific theory

Studies on productivity increase and reduced sick leave resulting from higher ventilation rates are used to determine financial additional gains. These two subjects will be discussed in this chapter.

Productivity increase

A number of laboratory studies have been carried out on the effects of individual elements such as temperature, air quality, lighting and noise levels, on staff productivity. These studies show that improving the quality of the air can already lead to a rise in productivity of 3 to 7%. Research, using objective parameters to measure productivity (typing speed, number of processed files, number of calls in a call centre), has shown that in situations like these a good indoor climate can promote increases in productivity of between 10 and 15%. [85]

In a study on weighting factor of building sustainability assessment scheme categories, environmental and economic assessment of available design options relevant for each category were translated to impact in Euros through energy and carbon prices and productivity costs. [86] The research was conducted in Estonia for a commercial 6 storey office building with a total user surface of 3830 m^2. Two different occupancy densities were used: 10 m^2 per person (office type 1) and 15 m^2 per person (office type 2). The salary of office employees used was €80 per day, resulting in a monthly salary of €1600.
The productivity was analyses for 2 occupancy densities and three ventilation rates according to the EN 15251 norm for three ventilation classes I, II and III (ACH ranging from 0.7 to 2.2). Equations derived from graphical presentation (Figure 26) of results originating from a study on ventilation and performance in office work was used [87]. Performance at all ventilation rates relative to the performance reference ventilation rates of 6.5 and 10 l/s-person are given in eq. (1) and (2). P stands for relative performance and L is ventilation flow rate in l/(s·person).

$$P = -0.00002L^2 + 0.002L + 0.9823 \quad (1)$$

$$P = -0.00005L^2 + 0.0033L + 0.9807 \quad (2)$$

In the study the positive effect on productivity due to class I ventilation in comparison with class III ventilation flow rate was determined using eq. (1) and eq. (2). This resulted in an increased productivity equal to 26.50 or 53.80 € /(m^2a) for office type 1 or 2, respectively.

For the LCC’ calculation the lowest cost reduction value of 26.50 €/(m^2a) was used for the increase productivity, since the ACH of U_{ref} and the nZEB scenarios (U_1, U_2, U_3) was 2 h^{-1} and 3 h^{-3}. Figure 26 clearly shows that the relative difference in productivity is lower between a ventilation rate of 30 and 45 (2 h^{-1} and 3 h^{-3}) compared to a ventilation rate of 15 and 30 (1 h^{-1} and 2 h^{-3}).

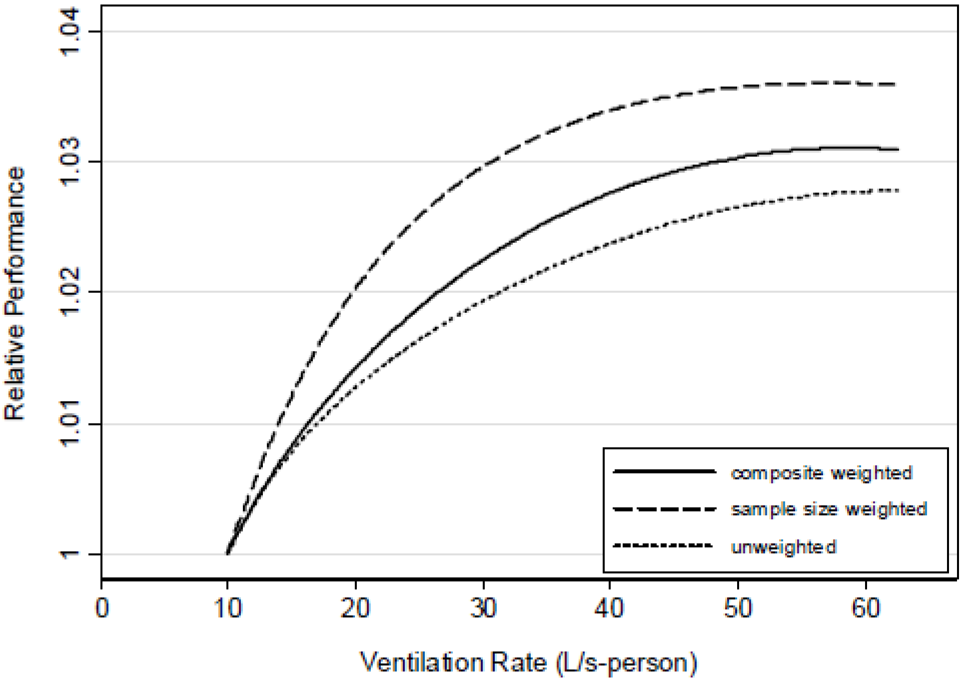


Figure 26: Relative performance in relation to the reference values 10 l/(s·person) versus ventilation rate. [87]

Sick leave reduction

In a paper on people's perception of the work environment, effect on productivity due to environmental quality (health problems and dissatisfaction) in Dutch office building was summarized. [85] The paper described two Dutch studies who revealed that a considerable proportion of sick leave can be attributed to quality of the workplace (complaints). Ambient factors of building and workplace considered were: temperature, air quality, individual climate control, noise, natural light and view, etc. [85]

The first report showed that 25 to 30% of total absence can be attributed to (building-related) health complaints, while another study concluded that about half of all employees occasionally stay home because of such complaints. Sick leave by unhealthy climate, averaged works out to 3.6 days per employee per year. The results were analysed more closely in another study with regard to this aspect, revealing a close correlation between sick leave (both number of occurrences and number of days) and building-related health complaints. A link has also been found between sick leave and the ability to adjust the temperature oneself, the presence of humidifiers and computer screen work.

For the LCC' calculation the average of 3.6 days per employee per year was used.

In a study on the economic benefits of an economizer system, benefits related to energy savings and reduced sick leave was investigated [88]. A model of the influence of outdoor air ventilation rate on airborne transmission of respiratory illnesses was used to extend the limited data relating ventilation rate with illness and sick leave.

An energy simulation model calculated ventilation rates and energy use versus time for an office building in Washington, D.C. with fixed minimum outdoor air supply rates (ACH ranging from 0.74 to 1.67), with and without an economiser. Sick leave rates were estimated with the disease transmission model. The office model consisted of an office area of 2000 m^2 with 72 employees (occupancy density of 28 m^2 per person) with a $2000 salary. A day of sick leave was valued at $200, based on annual total salary plus benefits of $50,000 and 250 work days per year.

Figure 27 shows the calculated values of illness or short-term sick leave versus ventilation rate, normalized by the illness or sick leave rate predicted with no ventilation. All predictions show the expected decrease in illness over time; however, the rate of decrease varies dramatically for low ventilation rates. The simple particle concentration model (black dots in Figure 27) provides a mid-range prediction and was used in the calculations.
Calculations were made for minimal ventilation rate of 10, 15 and 20 l/(s·person) with and without economiser. The minimum and maximum number of sick days, with and without economiser, showed a decrease when minimum ventilation rate was increased from 10 to 20 l/(s·person). The average additional number of sick days (for all 72 employees) was 35 days a year, for the case without the economiser for a minimal ventilation rate 20 l/(s·person). This means sick leave by unhealthy climate costs $7000 (35 x $200) annually.

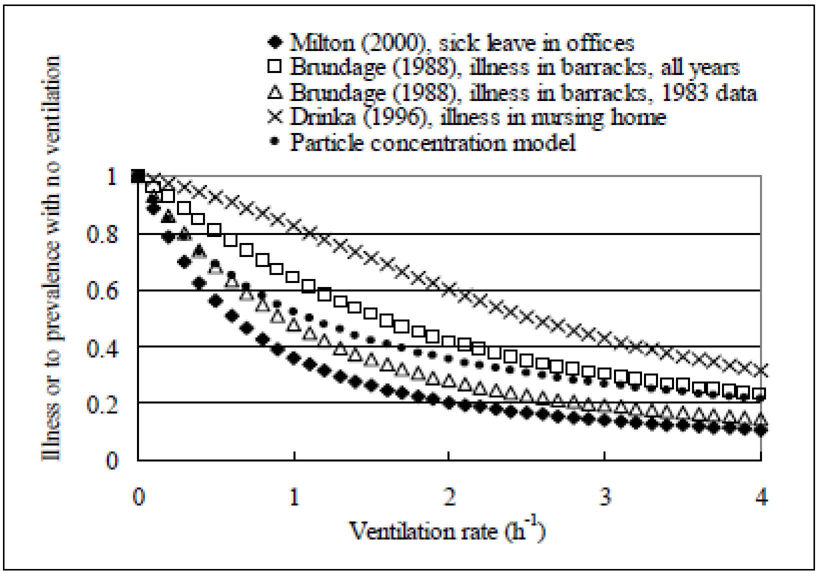


Figure 27: Predicted trends in illness or sick leave versus ventilation rate per unit volume. [88]

To determine the effect of ventilation rate on sick leave for the LCC' calculation, the minimum value of 35 days sick leave per year (spread over 72 employees) was used. According to the Bouwbesluit, values for ventilation rate have to be calculated according to NEN 1087 for specific office buildings. Due to lack of time a ventilation rate of 0.9 l/s per m^2 floor space was used, which corresponds to 27 l/(s·person) for U_{ref} (ACH of 2 h^{-1}). This value came closest to the ventilation rate difference of 2 h^{-1} and 3 h^{-3} used in the cost optimality.

5.3.2 Implementation

The additional gains (productivity increase and sick leave reduction) are implemented in the LCC' calculation within the OPEX. Additional gains not included in the LCC' calculation (higher rest value, PR value, higher renting price, gas grid connection) are also discussed in this section, which may be included in future studies.

Energy
These costs are specified in [€/(m²a)]

- *Gas price*: energy saving measures applied to the nZEB scenarios results in all-electric buildings, which have no gas connection. Because all buildings are all-electric, no differences appear (gas connection). When the nZEB scenarios would be compared to a gas grid connected building, cost can be further reduced.

OPEX
These costs are specified in [€/(m²a)]

- *Productivity increase*: The productivity increase was implemented using the cost reduction value of 26.50 €/(m^2a) from [86]. (also see chapter 5.3.1)
- *Sick leave reduction*: An average value was determined for sick leave reduction using the studies [85] and [88]. According to the first study, sick leave by unhealthy climate works out to an average of 3.6 days per employee per year. The second study is more specific (only looking at effects of en economiser on energy and cost) and results in averaged 35 additional sick days (spread over 72 employees) when no economiser is installed. This number corresponds to 0.49 sick days per employee per year. The average value, used in the LCC' calculation, was 2.05 days per employee annually. The office building in the current study is assumed to have 200 employees (15 m^2 / employee) with a monthly salary of €2000.
- *PR value*: The quantification of costs for PR value may be calculated with the budgets companies use for publicity on sustainability. Normally money would be spent on improving a production process (making products or services more energy efficient) which would be used for a greener image. The annual costs spending on those processes may now be spend a more sustainable building; the PR value of the building may be used for several years until regulation and other buildings have caught up to the nZEB standards.
- *Higher renting value*: this value is mostly represented by a combination of productivity increase, sick leave reduction and PR value. The reason this is mentioned is that these cost may or may not be incorporated in de LCC' calculation depending on whether the building owner is also the building user. When the building is rented, the higher renting value is most certainly lower than the combined gains (productivity, sick leave and PR value) because it is quite difficult to charge higher rent when values on number of employees, salaries, PR budget, etc. cannot be determined. This leads to the conclusion that it is more advantageous to own an nZEB.

End value
These costs are specified in [€/m²]

- *Higher rest value*: The value of building installation such as the ground source well for GSHP or ATES gives the building a higher end value. In the current study all buildings concepts (U_{ref}, U_1, U_2, U_3) have wells therefore costs/gains do not alter the outcomes of the LCC' calculation. However, the added value will be more significant when comparing nZEB scenarios with a conventional building with high efficiency gas boiler (no wells).

5.4 Results

The results of the micro and macro-economic analysis and the sensitivity analysis for office buildings are presented here. The building and installation specifications of the reference building and the nZEB scenarios can be found in chapter 4.2.2.

The graphical representations (figures) are shown in LCC' [€/m²] versus EPC demand for the case with and without additional gains. Appendix XII shows the results in LCC' [€/m²] versus primary energy demand [kWh/(m^2a)], also with and without additional gains.

5.4.1 Financial analysis

Cost optimality calculation for the office buildings is shown in this section. Important parameters used are:

- Inflation rate: 2.3%
- Discount rate: 6.4%
- Excluding CO_2 emission costs
- No subsidies
- Energy tariffs including energy taxes and VAT (Table 24)

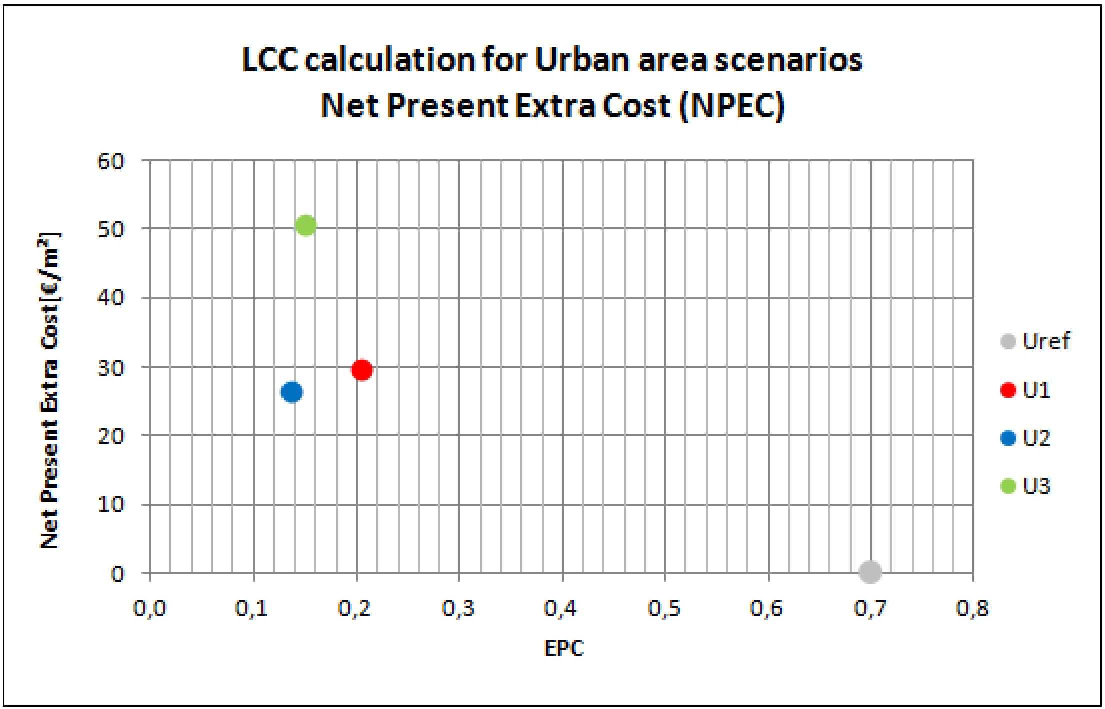


Figure 28: Financial analysis without additional gains for Urban area scenarios: office building.

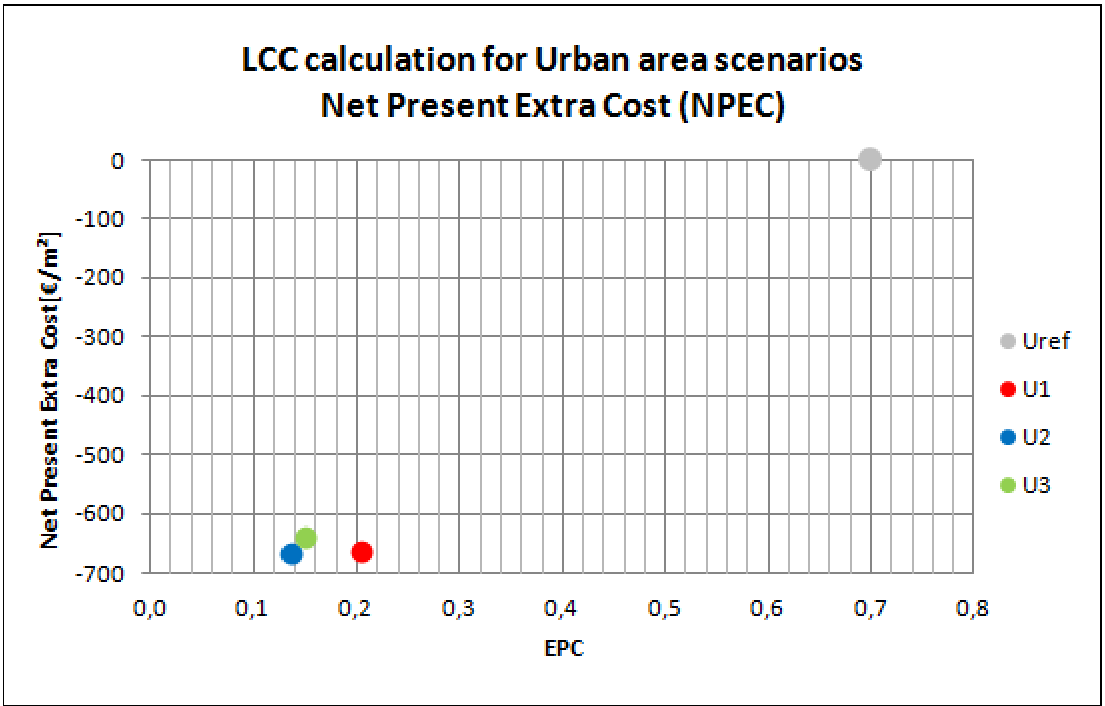


Figure 29: Financial analysis with additional gains for Urban area scenarios: office building.

5.4.2 Macro-economic analysis

Cost optimality calculation for the office buildings are shown in this section. Important parameters used are:

- Inflation rate: 2.3%
- Discount rate: 2.0%
- Including CO_2 emission costs: 42.50 €/(kWh·a)
- No subsidies
- Energy tariffs excluding energy taxes and VAT (Table 24)

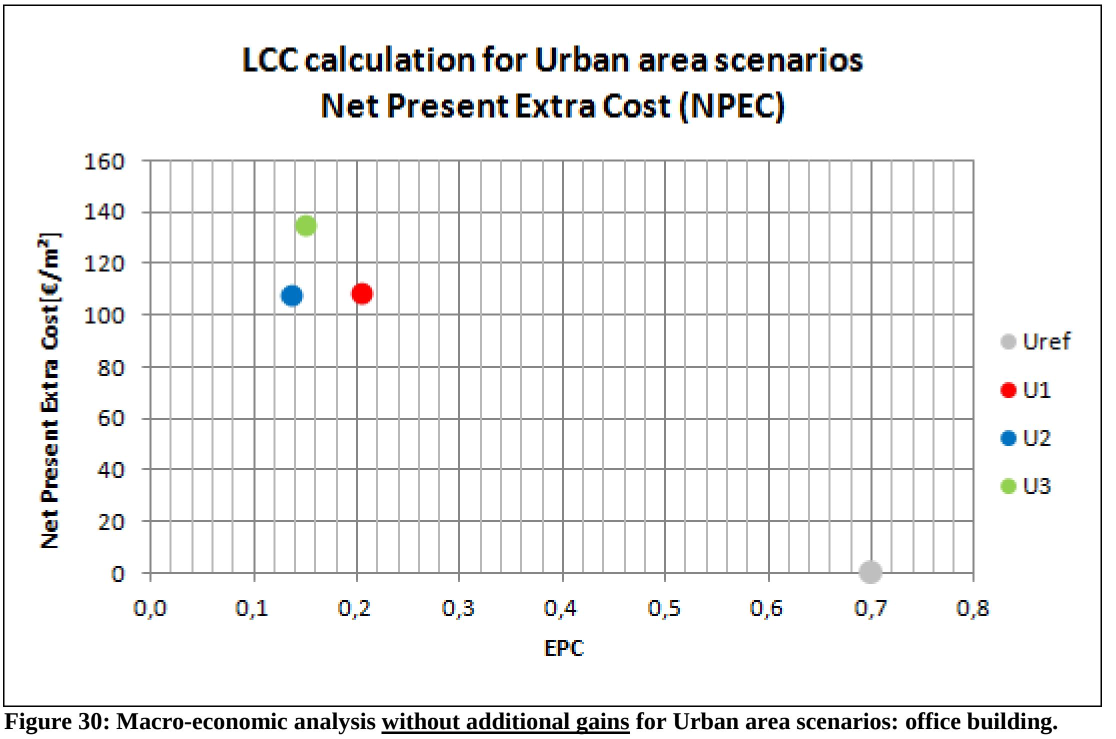


Figure 30: Macro-economic analysis without additional gains for Urban area scenarios: office building.

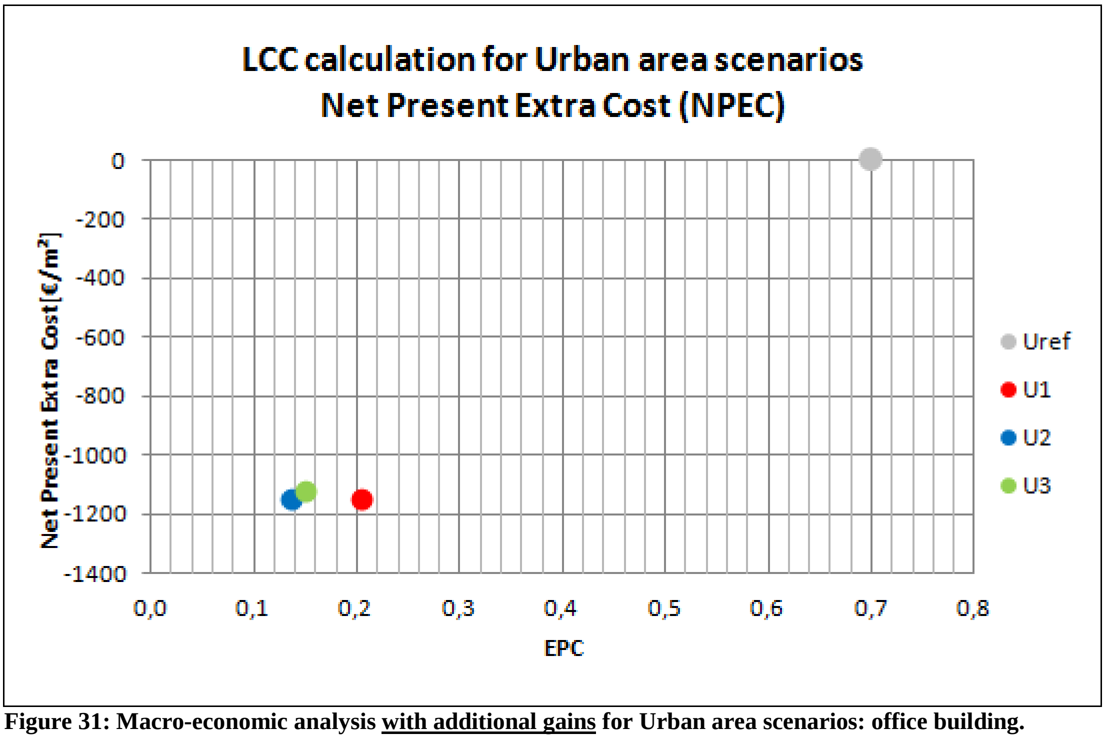


Figure 31: Macro-economic analysis with additional gains for Urban area scenarios: office building.

5.4.3 Sensitivity analysis

The sensitivity of several parameters is tested to determine the influence on the LCC' calculation. The sensitivity analysis (financial and macro-economic analyses) is conducted with additional gains only. Results of the sensitivity analysis are shown in Appendix XII. The sensitivity is determined for the alternative discount rates and energy price scenarios mentioned in chapter 5.2.2.

No surprising effects have been observed in the sensitivity analysis. The energy price scenario has small effects on both the financial and macro-economic analysis.

Financial analysis

Discount rate of 4.9% and 7.9% were used in the cost optimality calculation. The relative LCC gap between U_{ref} and the nZEB scenarios (U_1, U_2, U_3) is smaller for R = 7.9% compared to R =4.9% which is in line with the expectations.

Macro-economic analysis

Discount rate of 1.0% and 3.0% were used in the cost optimality calculation. The results are similar to the sensitivity of the financial analysis. The relative LCC gap between U_{ref} and the nZEB scenarios (U_1, U_2, U_3) is smaller for R = 3.0% compared to R =1.0% which is in line with the expectations.

Energy prices scenarios

For financial and macro-economic analysis price development -20% and +20% from the original 2.8% were calculated. The effect of the price scenarios had minimal effect on both the financial and the macro-economic analysis. The nZEB scenarios have a very little energy consumption, resulting in constant LCC. U_{ref} is of course influenced by the energy prices, resulting in better results for lower energy prices.

5.4.4 Discussion

The results of the cost optimality calculations are discussed in this section. Effects of on-site energy production on the cost optimality calculation are discussed.

An important factor in designing nZEBs was the application of PV panels. The EPC calculation method used in ENORM (according to NEN 7120) has a certain way of handling on-site energy gains into the building performance. It should be noted that all energy producing and consuming quantities calculated in ENORM are computed in primary energy values.
For small scale on-site electricity production by PV, all produced energy is allocated to the on-site consumption. However when a certain threshold is reached, the on-site produced electricity is not allocated to the on-site consumption but exported to the grid. Because all values in ENORM are computed in primary energy values, using different primary energy factors for on-site energy production and energy export, this results in an unfavorable (higher) EPC score. This means that additional PV electricity production can lead to a lower primary energy demand but EPC score that stays the same (or gets higher), as shown in Figure 32.

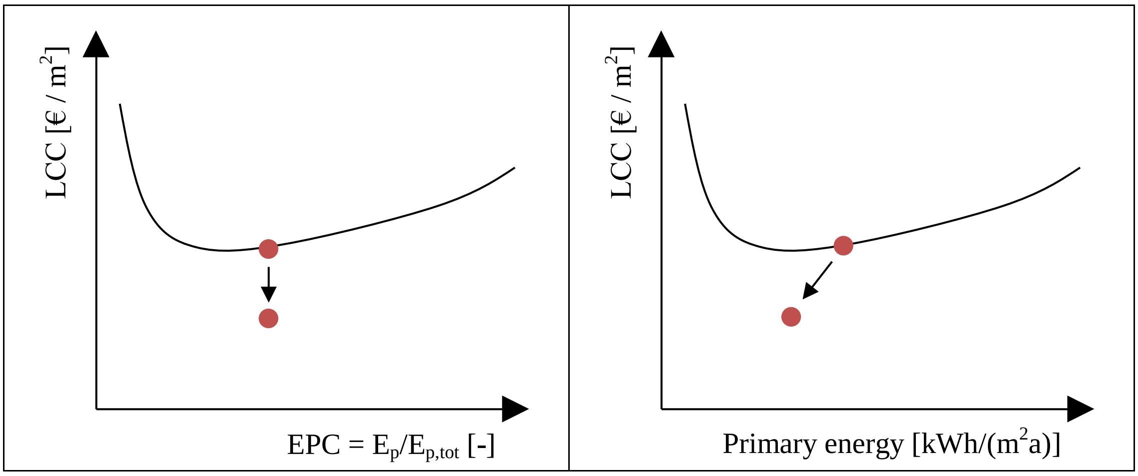


Figure 32: Cost optimality display: LCC versus EPC and LCC versus primary energy.

PV panels have a PBP of 5 to 10 years; therefore LCCs should decrease by increasing numbers of PV panels. It was expected that by adding PV panels both the EPC score and primary energy course would be similar, however from the Figure 32 can be seen that a difference between the EPC and primary energy is present. It is important to note that the EPC is a policy tool, which does not display the actual primary energy consumption correctly.

Continuing on on-site electric production, cost price of produced and consumed energy is of great importance to the BPB of PV panels. For cost calculations, it is important to known that all on-site energy annual production can be deducted from the annual consumption: the purchase price of energy (from a traditional energy company) can be used for both production and consumption. This means energy production and consumption can be added, resulting in a total energy demand.
When energy production exceeds consumption, a low selling tariff is applied (Table 25). This has consequences for the cost effectiveness of PV panels, since PBP increases. The low selling tariff discourages the potential for energy producing buildings.

Table 25: Electricity prices of generated solar power for different situations in [€ / kWh]. [89]

Price of generated solar power in different situations [€/kWh]						
	Small consumer ≤ 10,000 kWh		Medium consumer > 10,000 kWh		Large consumer > 50,000 kWh	For all consumers
	restitution ≤ 5,000 kWh and restitution ≤ consumption	restitution > 5,000 kWh and restitution ≤ consumption	restitution ≤ 5,000 kWh and restitution ≤ consumption	restitution > 5,000 kWh and restitution ≤ consumption	restitution ≤ consumption	restitution > consumption
Electricity price	€ 0.07	€ 0.05	€ 0.07	€ 0.05	€ 0.05	€ 0.05
Energy taxes	€ 0.11	€ 0.11	€ 0.04	€ 0.04	€ 0.01	€ 0.00
VAT	€ 0.03	€ 0.03	€ 0.02	€ 0.02	€ 0.11	€ 0.00
Total	€ 0.22	€ 0.20	€ 0.13	€ 0.11	€ 0.17	€ 0.05

5.4.1 Conclusion

The results presented in chapter 5.4.1 and 5.4.2 show positive effect of additional gains on LCCs over 30 year for both the financial and macro-economic analysis. Additional gains lead to cost effectiveness of all nZEB scenarios in both cases.

Figure 28 and Figure 30 show the cost optimality calculation without additional gains for the financial and macro-economic analysis, respectively. Both analyses show higher cost for the nZEB scenarios (U_1, U_2, U_3) compared to the reference building (U_{ref}).
In the financial analysis U_1 and U_2 are almost cost effective, with only 15 to 50 €/m^2 higher LCC compared to U_{ref}. The macro-economic analysis does show a LCC gap between the nZEB scenarios and U_{ref}, which is quite considerate: 100 to 140 €/m^2. The NPECs (Net Present Extra Costs) of the nZEB scenarios are two to three times higher for the macro-economic analysis compared to the financial analysis. This effect results from the energy taxes and VAT, which is included in this calculation.

Figure 29 and Figure 31 show the cost optimality calculation with additional gains for the financial and macro-economic analysis, respectively. Both analyses show major improvements: the LCC's in the financial analysis are reduced by 650 €/m^2, while LCC's in the macro-economic analysis are reduced by 1100 €/m^2. In the sensitivity analyses, the LCC gap between U_{ref} and the nZEB scenarios fluctuates for both analyses; however they do not influence the positive outcome of the LCC of the nZEBs.

It can be concluded that nZEB scenarios U_1 and U_2 are most promising, taking the financial and macro-economic analyses in consideration.

6 Discussion

This chapter discusses the limitations of this research, focusing on the literature used and the scope of the cost optimality calculation.

Diverse sources have been used for this report: mainly reports from governmental agencies, expert institutions and scientific literature. A complete reference list can be found on pages 66-71 and important sources (and their use) are shown below:

- *Agency NL*: Information on nZEBs, Dutch nZEB policy, reference buildings, Smart Grids.
- *European Commission*: EPBD, additional directives on cost optimality calculations.
- *REHVA*: Articles on nZEBs, nZEB definition, innovative techniques, nZEB status Europe.
- *TVVL*: Articles on innovative technologies.
- *CA EPBD*: Reports on current nZEB status EU member states.
- *TU/e*: Information on existing nZEBs and building energy saving measures.
- *Science Direct*: Papers on building energy saving measures.
- *dGmR*: Reports on cost optimality calculations.

Other relevant sources for this report are: BPIE, ECN, SustainCo, AIDA, The Policy Partners (renovation roadmap), Eurima, Netbeheer Nederland (Smart Grids), CBS (building density), EWEA (wind energy), RCI, REAP.

Initially the focus of this research was on cost optimality calculations for three distinct areas (urban, suburban, rural) with corresponding reference buildings. Due to time constrains, calculations have only been performed for a middle sized office building in the urban area.
The reference office is based on a building (from Agency NL) with 4 floors and a user surface of approximately 3000 m^2 (Ch. 4.2). The reference case is compared to three nZEB scenarios to which energy saving measures have been applied. Energy saving measures were chosen one basis of their technical and financial potential, and proven applicability. The number of nZEB variant was limited due to the LCC’ calculation tool which only enables to compare four buildings.
The LCC’ calculations in this report are based on dGmR reports [79][80] and RHDHV reports [81][82], and adapted to the EU calculation method mentioned in notices from the European Commission [6].
Additional gains have been added to the ‘standard’ LCC calculation (prescribed by the EU), introducing a new term: LCC’. The gains that are included in the LCC’ calculation are increased productivity and reduced sick leave. A simplistic approach was applied to incorporate these factors in the calculation. Other gains that have not been included are: PR value, higher renting value and higher rest values. These gains were difficult to quantify and it was (in some cases) unclear to which party these costs/gains should be allocated.

7 Conclusions and recommendations

This study on nZEBs in the Netherlands has provided insight in the current situation of nZEBs and promising scenarios which are technically and financially feasible. The aim of this report was to give information on nZEB developments that will occur in the near future and what the consequences of these developments have for buildings, in particular for building services.

The Netherlands has good potential for nZEBs with regard to newly built and existing buildings. While the nZEB definition in the Netherlands has not been defined yet, technical and financial potential are present to support future nZEB regulation. Provisions have been made to tighten EPC demands in 2015 and 2017 for the residential and utility buildings, respectively.
Examples of nZEBs (residences, offices and schools) show the technical capabilities of energy saving measures: low EPC scores can already be achieved. Existing energy saving measures have been compared to measures applied to nZEBs: it clearly shows focus should be on energy saving (insulation, glazing, and air tightness) and installations (heating/cooling system, mechanical ventilation with heat recovery and application of large scale PV).

The energy infrastructure in the Netherlands needs to undergo a transformation to support the implementation of nZEB buildings to the existing grid. Currently many different smart grid projects are being executed ranging from an energy neutral business park to a complete or partial self-sufficiency in heat and electricity network, powered by biomass CHP production. It is expected that smart grid (pilot) projects provide good outcomes which enable large scale implementation of smart grids.
Three nZEB infrastructure scenarios have been discussed for urban area, suburban area and rural area. These scenarios focus on energy exchange between buildings (urban area) and local smart grids with collective heating and cooling systems (suburban area). Integrated energy saving measures (PV, solar collector, PVT) are also applied in all areas.

Building services will have to focus on the adapted Trias Energetica approach, where the building user needs become a preceding step in designing an nZEB. This means climate systems should be adapted to each building-user specifically: providing climatisation were needed. Techniques that can be applied are: (individual) climate zones, workplace thermal systems, and presence detection.

In the following paragraphs conclusions are drawn on several subjects treated in this report. Recommendations or improvements for further investigation will also be given.

nZEB definition: the Dutch nZEB definition has not been defined by the government yet. Recently (January 2014), the Belgian government has defined building energy performance requirements for nZEBs; the energy performance of residential buildings is set to 70 kWh/m^{2}a. To compare, in the Netherlands a terraced house (in-between-dwelling) with an EPC of 0.5 has a primary energy demand of 71 kWh/m^{2}a. Currently Dutch regulation requires an EPC demand of 0.6. This shows that Belgian nZEB demands (for residential buildings) are not as rigorous as in the Netherlands. It is expected that the Dutch nZEB definition for residential buildings will be around 30 to 50 kWh/m^{2}a (EPC of 0.2 to 0.4).
On basis of this study (in line with dGmR reports [79][80]) a recommendations is done on EPC demands for offices. For a middle sized office building it was possible to create nZEB designs with an average energy consumption of 20 kWh/(m^{2}a) resulting in an EPC score of

~0.2. On basis of this study, an EPC of 0.2 for offices is recommended since it is technically feasible, and financially (taking into account additional gains) more attractive than an office building with EPC 0.7.

Energy saving measures: from a technical and financial point of view buildings with GSHP or ATES heating/cooling systems are most promising in urban area. Their wide applicability (Appendix VI), knowledge available in the Netherlands, and financial feasibility (chapter 5.4.4) makes them very attractive. Furthermore large scale PV application should be utilized in order to obtain an nZEB.

Nearby energy production: in the EPBD, nearby (off-site) sustainable energy production is mentioned to be contractually linked to a building (site). Fitting legislation should be in place to stimulate on-site production, and minimize the possibility to be sustainable 'on paper'; meaning that buildings should utilize maximum amount of sustainable on-site energy, before contractually link the building to e.g. off-shore wind turbines.
Renewable energy production techniques such as PV panels and solar collectors are influenced by the built environment, especially building density. Also for GSHP or ATES systems, limited space reduces applicability. It is therefore advised to consider a legislative system determining on-site sustainable energy yield depending on the building density. For example a certain percentage of renewable energy may be contractually imported when a building is located in a dense area; the rest would have to be generated on-site.

Degradation energy saving measures: it is important to realize that building performance reduces over time, because energy efficient measures (building and installation) degrade over time. Performance guarantees of PV panels used in this study are: 90% of performance is guaranteed over 10 years, 80% of the performance is guaranteed over 20 years. ENROM, the calculation tool used to determine the primary energy demand, does not take this into account. Other critical aspects for PV panels, especially placed on the facade, are shadow of threes which grow in the course of the 30 years. For insulation materials a lifetime of 50 years was assumed, however the performance of the material may degrade over time. In future calculations degradation of energy saving material should be included in calculation to obtain more accurate results.

EPC versus Primary Energy: the EPC is does not represent the energy consumption in a straightforward way, resulting in differences between the EPC values and the primary energy demand. The EPC is a Dutch policy tool which display building energy performance, and it can be utilized for comparison of building energy performance. However, the actual primary energy demand may differ from EPC; this could result in a building with higher EPC score, but lower primary energy demand.
Most critical point of attention between EPC and primary energy display is the on-site energy production. The EPC calculation (according to NEN 7120) makes a distinction between on-site utilized energy and exported energy. On-site energy production is divided into on-site utilisation and exported energy, dependent on the amount of energy consumption related to 'non-installations' (all building installations excluding appliances). Above certain energy consumption limit, all on-site energy is exported to the electricity grid. This calculation method can negatively influences the EPC score, while the net primary energy reduces. This effect is also shown in Figure 32.

Electricity tariff produced energy: it is unattractive to become an energy producing building with current regulation. Energy tariffs for electricity produced (e.g. by PV panels) are considerable lower than energy prices of imported energy (Table 24 and Table 25), when more electricity is produced than consumed annually. When current regulation on energy tariffs still applies in the future, it is recommended to define nZEB as buildings with a primary energy demand limit slightly above zero e.g. 20 kWh/(m^2a): this can prevent energy efficient measures from becoming financially unattractive.

Broader range of nZEB scenarios: more investigation is needed on energy saving measures to define a wider range of nZEB design scenarios. Studies similar to the dGmR report [80] for nZEBs would sketch a broader view on the possible measures for different building types. It is recommended to investigate all building functions according to the Bouwbesluit and apply at least ten energy saving packages per building function.

Additional gains - productivity and sick leave: the additional gains proved to reduce LCC of nZEB considerably, shown in chapter 5.4. It should be noted that simplistic methods have been applied to incorporate the gains into the LCC' calculation. Research used originated from studies which had a comparisons between a base cases with lower building performance (ventilation rate), than the base case for this study. For both additional gains (productivity and sick leave) values were used closest to the building performance of this study; however a certain deviation exist. An example of this difference can be seen in Figure 26 when comparing performance increase between lower and higher ventilation rates. To gain more reliable results, more specialized calculations on increased productivity and reduced sick leave should be conducted for ventilation rate used in this study: $ACH_{ref} = 2\ h^{-1}$ and $ACH_{nZEB} = 3\ h^{-1}$. This may lead to lower additional gains, however it is expected that the gains still lead to positive results (cost effectiveness) for the nZEB scenarios.

Additional gains – not incorporated: in this report additional gains are mentioned that are not taken into account in the LCC' calculation. Gains that should be further investigated are: PR value, higher renting value, and higher rest value. The potential to implement these gains has been explained in chapter 5.3.2. Further investigation on these subjects is necessary to define actual costs. It was concluded that owning and using an nZEB is more beneficial than of renting an nZEB to another party, because the additional gains of a higher renting price is probably lower than the benefits of productivity and sick leave.

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Appendix

Appendix I Internship assignment description

TVVL roadmap to nZeb
powered by Royal HaskoningDHV in co-operation with Eindhoven University of Technology

Introduction
The nearly zero energy building is one of the issues to be solved regarding sustainability in the built environment. New upcoming legislation from the European committee on this topic will be implemented in the coming years. What is the definition of nearly zero? Each member state will be able to define its own nearly zero approach. Which scenarios are promising?
TVVL and RHDHV/TUe want to:

- Give information and insight in nZeb developments that will occur in the near future and what the consequences of these developments are for Buildings and in particular for Building Services.
- Contribute to the road to nZeb and help our society to make the right choices.

Inventory
An inventory will be set up on the actual level of research in the Netherlands and in Europe. What is coming ahead?
What is the definition of nzeb, what are the levels of nearly zero in other member states, what are the system boundaries?
Desk and Field studies will be performed:

- The desk study consists of gathering and analyzing information on the EPBD recast in the Netherlands and on EU-level. Relevant information can be found and accessed using the following connections:
  - RHDHV supports the Dutch government (AgNL-BZK) in all kind of projects (implementation EMG, "aanscherpingsmethodiek", cost optimality) regarding the implementation of the EPBD recast. This information will be very valuable to the inventory.
  - Wim Maassen (Leading Professional Sustainability and Life Cycle Costs at RHDHV) is also Fellow Life Cycle Performance Design at the EUT working together with Prof. Wim Zeiler (Building Services). This, together with the input of a graduate EUT student ensures the input of the EUT on the road to nZeb and the role and consequences for Building Services.
- The field study will consist of Interviews with stakeholders, universities, ISSO, Rehva, internet surveys are the basis of the research.

Technical feasibility
Create a level of nzeb that's socially responsible, cost effective (and/or beyond cost optimal) and meets government needs, what is a feasible level of nearly zero using for instance:

- An effective building concept;
- Minimizing losses and optimizing energy use and real demand, eg workplace climatization and smart control strategies (Human in the loop systems);

- Passive building approach;
- Local generation of sustainable energy, eg sun, wind, soil;
- Smart grids;
- Sustainable Energy storage;
- Bio fuels, are they competitive as energy source in relation to the world needs on food, or "bypass"-CO_2-generation (transportation);
- Is it useful to scale up system boundaries in order to take advantage of energy demand and energy needs between buildings or even a residential area or a district with offices;

Using the techniques on building level, especially Building Services, there should be distinguished between:
- Existing techniques
- Techniques in development
- Future techniques

Financial feasibility
Futhermore the cost optimality of these techniques should be determined according to NL cost optimality calculation based on the EU-EPBD recast calculation framework. This cost optimality calculation is based on a Life Cycle Cost Calculation over a longer period than 20 years.

Benefits and Scenarios
In addition to the EU framework for cost optimality calculations besides costs also benefits and scenarios should be considered.

Benefits should be considered because they provide incentives for nZeb Building Designs that lay beyond the cost optimal level. Benefits to be considered are:
- higher productivity due to higher level of indoor climate
- higher rest value
- CSR value – nZeb helps the organization to realize their sustainable goals
- PR value – resulting in higher turnover and profit of organizations.

Scenarios should be applied to anticipate as well as possible on changes in the future. Scenarios consist of all kind of changes that may occur in the future, e.g:
- future usage of the building including building functions, m2, number of people
- level of required building performances: Energy/CO2-emissions, Measurable sustainability (LEED/BREEAM/Greenstar/QSAS), Indoor climate conditions, ...
- climate conditions
- availability of resources and their costs
- availability of new and innovative techniques and their costs
- financial parameters: inflation, discount rate, ..

Results:
This results in a report that consists of the following:
- Inventarisation (Desk and Field study)
- Cost optimality calculations and conclusions:
  - According to EU frame work
  - Also including Benefits
  - Also including scenarios
- Overall conclusion on feasibility of nZebs and the consequences for Building Services in particular.

Appendix II nZEB examples

Single family house

In the village of Grijpskerke in the province of Zeeland a CO_2 neutral street (Picture 3) with single family houses has been realized in 2011. For these houses a combination of active and passive techniques has been applied. The dwellings are very well insulated and equipped with efficient ventilation and heating system with heat pump or pellet boiler. Electricity is generated using a PV roof, which makes the dwellings CO_2-neutral. The dwellings have also been equipped with smart meters and domotica (integrated system which actively think with the building), which makes it able for residents to monitor the energy generation of solar panels and to see whether energy is extracted from the grid or supplied to the grid. These houses are actually zero energy buildings since they have and EPC of -0.09 (energy producing). [91]

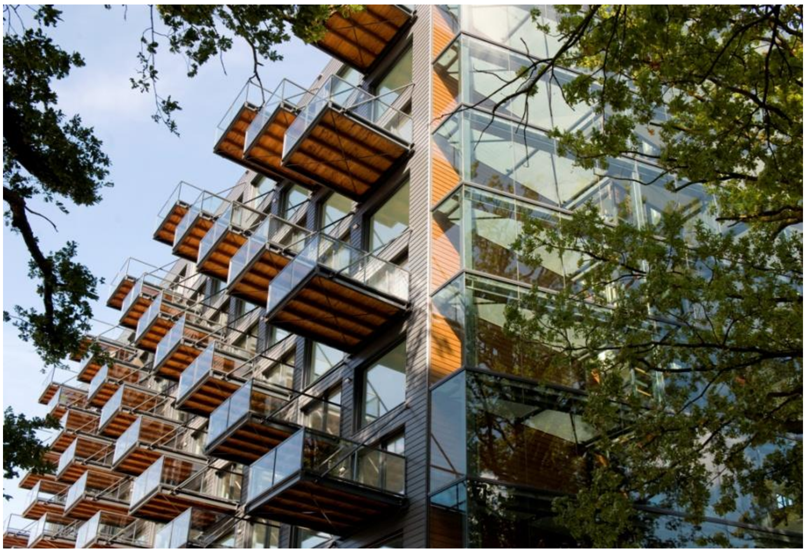
Picture 3: CO_2-neutral street in Grijpskerke, Zeeland. [33]

Apartment block

The Kotmanpark Energy Efficient apartment block (Picture 4) in Enschede is a building complex which was realized in 2011 inspired by the 'Passive House' concept. An EPC of 0.48 was achieved by reducing the heating demand as much as possible and generate the energy as sustainable as possible. Reducing heat losses has been accomplished by orienting the building towards the sun, using insulation material with high heat resistance (R_c = 7-10 m^2K/W), and reducing cold bridges by making the building extremely air tight. [92]

Solar collectors in combination with an individual heat pump boiler are used to provide hot tap water. All 54 apartments are heated by low temperature heating using floor heating.

This building has a monitoring system installed which is used for energy behavioural changing purposes. For all apartments monitoring systems were applied, but for 10 apartments a detailed monitoring system is used to give direct feedback to the users which influence their energy consumption.



Picture 4: Kotmanpark Energy Efficient apartment block in Enschede. [35]

Office building

The WTH headquarter (Figure 33) was built in 2003 and has an energy label A++ (EPC = 0.36). The building has a total floor space of 4100 m^2 of which 1900 m^2 is a production facility. The cooling function of the climate installation of this building has high priority since internal heat gains and a well insulated building envelope can lead in high risk of overheating. Therefore the office has and ground source heat pump in combination with passive cooling. Low temperature heating and high temperature cooling is combined with the earth sources and additional asphalt collector (‘road energy’) for regenerative or free cooling. Most of the building is equipped with floor heating but some walls also provide cooling. The ground sources consist of two hot wells (15°C) and two cold wells (8°C) at a depth of 127 meter. Double glass with a U-value of 1.50 W/m^2K and insulation with R_c-value between 3.50 and 4.50 is applied to reduce heat losses as much as possible. A ventilation system using high efficiency heat regeneration further reduces losses. [93]

The building has two special features: the roof of the building fitted with 400 m^2 so called ‘solar tracks’ with integrated light receptors. These tracks improve sun reflection (reducing cooling demand), have a life span twice as long as traditional bitumen roofs and is completely recyclable. The parking space is heated using surplus of heat from the hot well, ensuring an evenly annual heat and cooling demand.

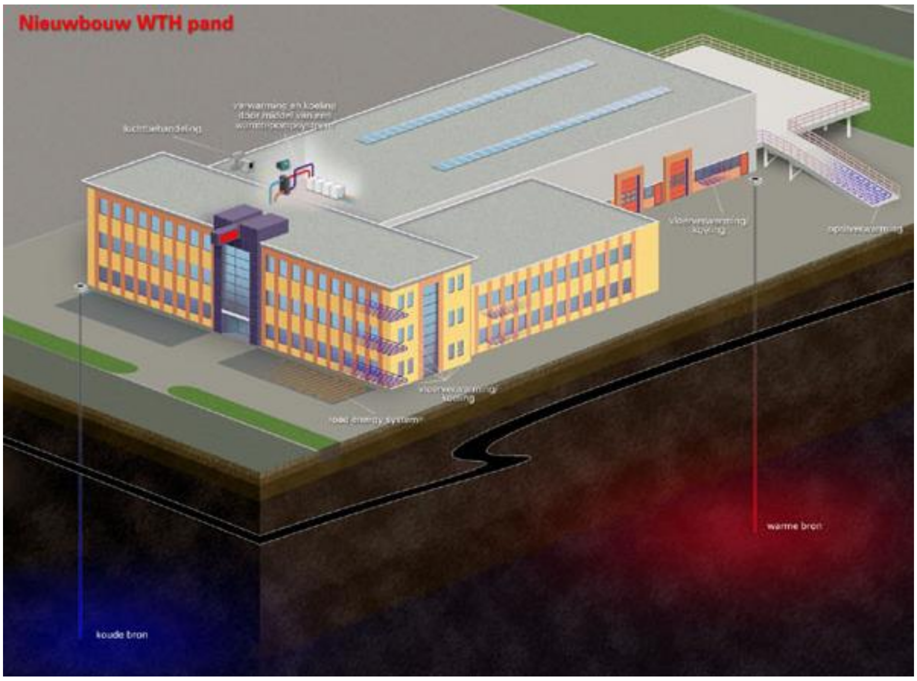


Figure 33: WTH office in Dordrecht. [94]

School - RHDHV nZEB project

Royal HaskoningDHV was involved in designing the technical installation for an elementary school in Haarlem, part of 8 UKP-NESK-school projects. UKP NESK stands for Unique Opportunity Program to Energy Neutral Schools and Offices. The school was built in 2012 and is completely energy neutral (ZEB) with an EPC of 0.

The elementary school has a total user surface area of 3900 m^2 including a gym (600 m^2) and a preschool play area ('peuterspeelzaal') (100 m^2). The municipality of Haarlem and Spaarnesant launched the UKP-NESK to build an energy neutral primary school in their region. The building design is by CASA Architects and the civil design was by DSK. Merosh provided technical installations and recommendation on building energy performance supported by RHDHV.

Heating and cooling is provided by aquifer system where heat and cold is stored underground. A heat pump exchanges the heat from the underground heat exchanger to the delivery system. Concrete Core Activation (CCA) is used to retain heat in the building for longer periods. [95] The energy demand of the building has been minimized by optimal geometry towards the sun and very high insulation values (R_c = 8 m^2K/W). The building has a CO_2 regulated ventilation system using large air channels, for optimal air quality and reducing ventilation power. Furthermore heat recovery is applied with an efficiency of 90%.
The roof and façade of the building are covered with PV panels with a total surface of 820 m^2. LED lighting is applied as much as possible to reduce electricity demand. [96]

Special features that have been implemented in this building are:

- One main (server) computer is installed in the building, from which rest heat is used for hot tap water. All other computers in the building use small computers (creating limited heat), making temperature control more effective.
- A dishwasher which uses heat recovery.

A special arrangement with the contractor and the installer is in place which ensures monitoring of the building energy performance two years after completion. The contractor and the installer are accounted for the building performance by postponed payments for building installation, assuring involvement afterwards.

Figure 34: DSK II Brede elementary school in Haarlem; a) 3D view and b) floor plan of the ground floor. [97]

Appendix III Reference buildings

Terraced house

Figure 35: Geometry in-between-building terraced house. [90]

Table 26: Properties of the terraced building. [90]

Kenmerken van de woning		
Beukmaat	5,1	m
Woningdiepte	8,9	m
Verdiepingshoogte	2,6	m
Gebruiksoppervlakte A_g	124,3	m^2
Verliesoppervlakte $A_{verlies}$	156,9	m^2
Verhouding A_g / $A_{verlies}$	0,8	m^2
Buitenzonwering op (manual)	zuid	

Apartment block

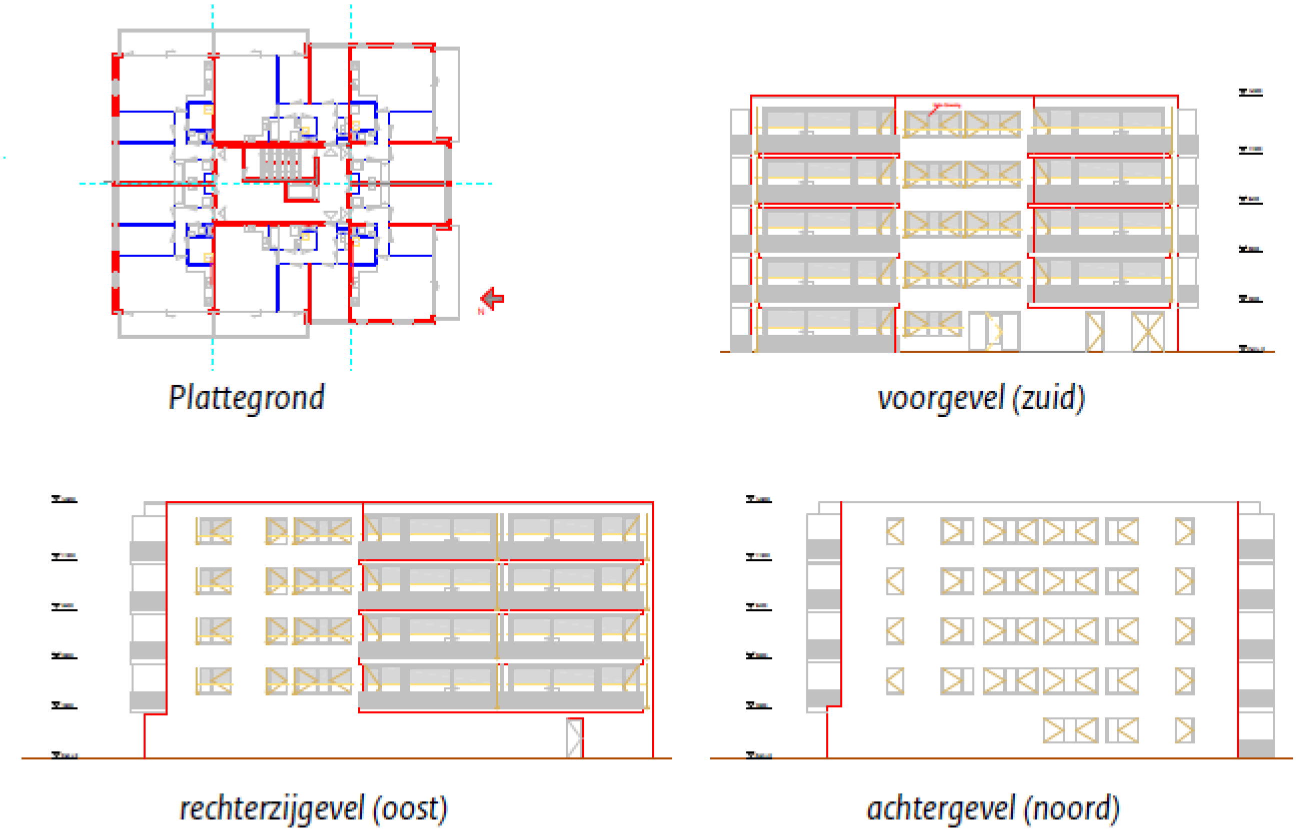


Figure 36: Geometry of the apartment block. [90]

Table 27: Properties apartment dwelling. [90]

Kenmerken van de woning		
Beukmaat	8,3	m
Woningdiepte	11,9	m
Verdiepingshoogte	2,6	m
Gebruiksoppervlakte A_g	92,1	m^2

Table 28: Properties apartment block. [90]

Kenmerken van het woongebouw		
Aantal bouwlagen	5	-
Aantal woningen	27	-
Gebruiksoppervlakte A_g	2756,3	m^2
Verliesoppervlakte $A_{verlies}$	2644,6	m^2
Verhouding A_g/ $A_{verlies}$	1,0	-

Terraced house

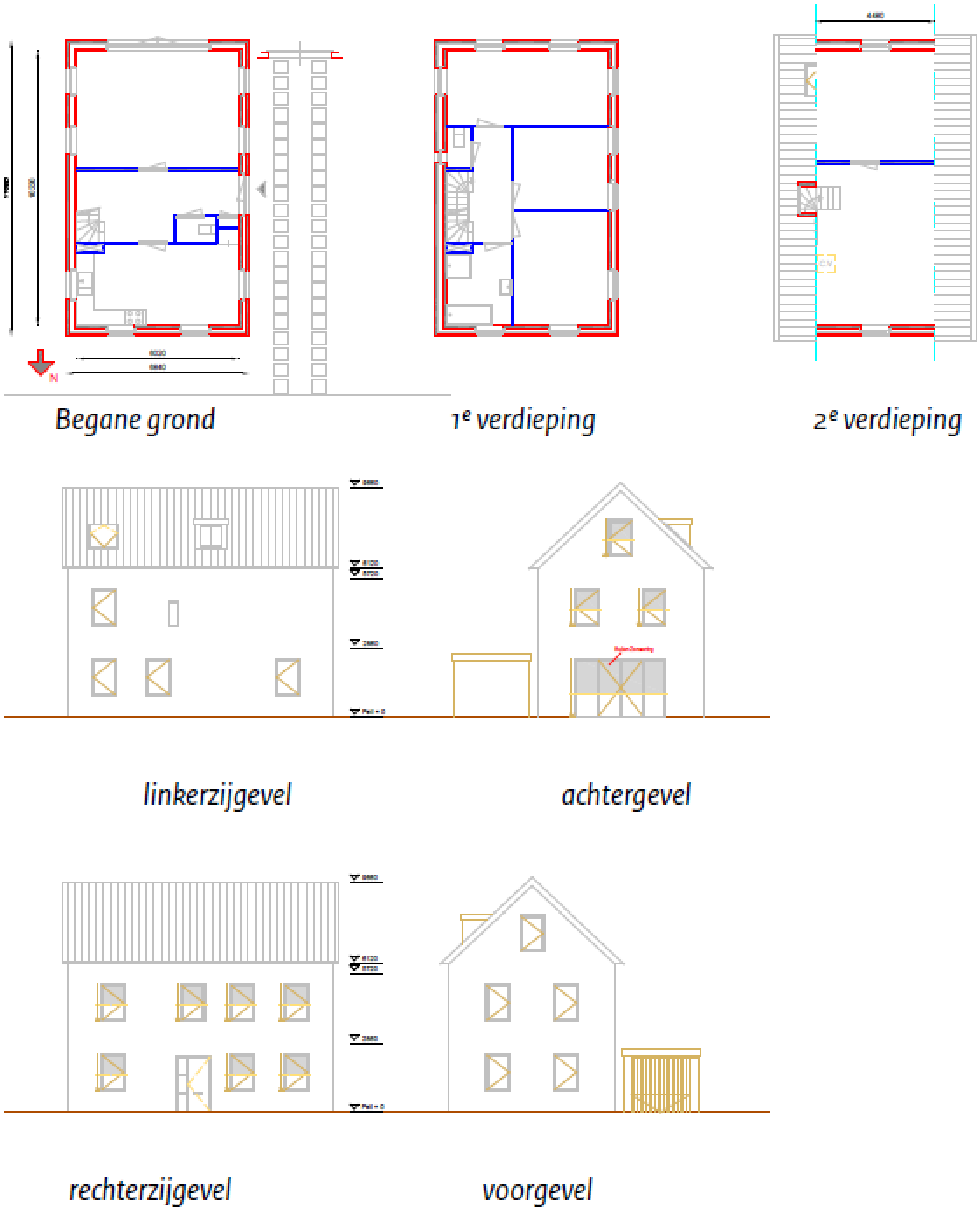


Figure 37: Geometry of the detached house. [90]

Table 29: Properties detached house. [90]

Kenmerken van de woning		
Beukmaat	6,0	m
Woningdiepte	10,2	m
Verdiepingshoogte	2,6	m
Gebruiksoppervlakte A_g	169,5	m^2
Verliesoppervlakte $A_{verlies}$	358,4	m^2
Verhouding A_g/ $A_{verlies}$	0,5	-

Appendix IV Smart grids examples

This appendix describes three smart grid example projects in the Netherlands. All projects are focussed on residential districts on different scale (25, 266 and 3000 dwellings). The projects also differ in type of network (electrical of heat) and renewable energy generation used (PV panels, GSHP, biomass boiler).
Projects include a pilot project with smart-meter residences; a collected GSHP residential district; and a large biomass installation providing heat for 3000 houses [98]. The projects are discussed in the following paragraphs.

Your Energy Moment
The newly built residential district Muziekwijk in Zwolle (completed in 2014) is a smart grid in which 266 residences are accommodated with a PV-system, a smart meter, smart appliances (washing machine) and an energy computer. The project is collaboration with Enexis and SWZ; Enexis provides the electrical network connection connected to smart metering and SWZ has made the buildings compatible for the network and provides the PV panels (1000 kWh/a) and corresponding systems installations. [99]
Residents of rental and owner occupied buildings can actively participate in this pilot project with a total duration of 24 months. By regulating the demand and supply of electrical energy, appliances will be run at times of lower energy prices and energy produced with the PV cells can be used more efficiently. [100]

Power Matching City
In 2010 the project Power Matching City (PMC) was founded by the co-operation with KEMA, ECN, Essent and Hurnig. The project is divided in three parts of which the second phase is currently underway. The goal of the project is to gain knowledge for companies associated with smart grids for reference of future larger scale projects. [99]
PMC I (running from 2007 to 2011) was a small scale project in which 25 houses were provided with a micro CHP, hybrid heat pumps, PV cells, smart appliances and electric cars. The result showed that it is possible to optimize energy services for a small scale district.
PMC II, started in September 2011, uses results of the first project and expanded the number of buildings (50 to 70 households) and extending the number of electrical vehicles with smart charging services. They will focus on the development and demonstration of business models for new services. New propositions will be offered to the end-user, based on real-time pricing. The market model of PMC will be integrated into regular energy market processes like allocation, reconciliation and billing. [101]

Bio Energy Vallei
In the city of Ede two residential districts (Kernhem and Veldhuizen) with 3000 houses and a swimming pool will be provided with heat by a bio-energy plant. The project duration is set at 15 years and the aim is to achieve a CO_2 reduction of 7,000 ton annually compared to conventional fossil fuel heating systems. [102]
The biomass boiler heats up water which is pumped to the district 5km from the plant. Biomass, primarily wood chips from local forests, is provided to the plant which has a power output of 4.5 MWth. Future expansions is possible by adding a second plant (total power output 9 MWth), depending on the heat demand of the houses.

Appendix V Building energy saving measures

This appendix describes building technologies that are interesting for nZEBs. The following distinction between techniques at building level is made:

[A] Conventional energy saving measures
[B] Energy saving measures in development
[C] Future energy saving techniques

All relevant techniques for nZEBs are discussed in the following paragraphs. The main focus will be on building installations utilizing renewable energy sources.

[A] Conventional energy saving measures

The following existing building techniques will be discussed:

- Ground Source Heat Pump (GSHP) – closed system
- Aquifer Thermal Energy Storage (ATES) – open system
- Deep Geothermal systems
- Combined Heat and Power (CHP)
- Solar Collector (SC)
- Photovoltaic's (PVs)
- Rest heat
- Wind energy on national level

Ground Source Heat Pump

GSHP systems are closed loop systems in which ground heat exchangers are used. Two types of layouts exist: vertical systems and horizontal systems. (Figure 38) In the Netherlands a vertical GSHP is more convenient because of limited space, however when large building plots are available horizontal systems can be applied as well. For vertical heat exchangers, the heat exchanger may be pressed into the ground (typically in weak soil) or may be inserted into a drilled borehole. Usually depths of vertical boreholes are within a range of 20 to 250 meter. Depths and number of boreholes are dependent on factors such as the capacity of the heat pump, soil type and available space. Typical costs for vertical boreholes in the Netherlands are about 30 euro per meter. [91]

Figure 38: GSHP closed loop system: a) vertical heat exchangers and b) horizontal heat exchangers [104]

Figure 51 and Figure 52 in Appendix VI show the heat and cold potential from vertical heat exchangers in the Netherlands. The average annual heat extraction is over 1000 GJ/ha and cold extraction is 450 GJ/ha. The suitable ground makes GSHP systems in the Netherlands very attractive for both individual as collective building heating applications.

Closed boreholes systems are not registered in the Netherlands, but it is expected that currently thousands of systems are in use. The application of closed loop GSHP systems in the Netherlands is falling behind compared to other European countries. In the Netherlands emphasis is on large open (aquifer) systems with high power output. However enough experience and knowledge on closed GSHP system present with Dutch suppliers. [105]

Costs of GSHP systems (electrical heat pump in combination with heat exchangers) vary widely and depend mainly on the capacity. In the Netherlands costs are around €14,000 to €20,000 for individual systems with a capacity of 10kW. Collective systems (with 10 to 40 dwellings) reduce costs to be around €10,000 per dwelling. Installation costs of GSHP in large scale renovation projects are between €10,000 and €15,000. Retrofitted systems are usually fitted in (older) smaller dwellings with a smaller capacity between 4 – 10 kW. [105]

Aquifer Thermal Energy Storage

In ATESs, heat is not extracted from the ground by indirect means via a heat exchanger, but directly through extraction of the ground waters. Aquifers are natural water carrying layers in the ground that have such high permeability that the water can flow through easily. [91] In the Netherlands, a large part of the country has suitable aquifers layers as shown in Figure 53 (Appendix VI).

In practice, three different types of aquifer systems are used for heat and cold storage. [91] A default system layout is shown in Figure 39. This system has a hot well and a cold well a different horizontal locations (‘doublet’).

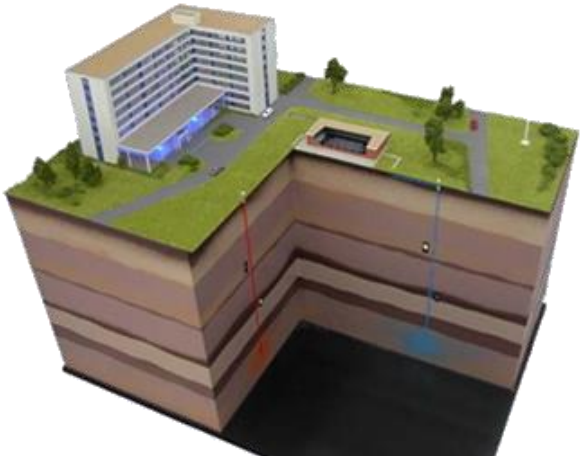


Figure 39: ATES ‘doublet’ system. [106]

The distance between the wells is determined by the required storage capacity; if the distance is too small, water inserted in the hot well will reach the cold well at some point during the season, degrading the system performance. Too large distance between the wells may leads to additional pressure drop which leads to increased pumping power (lowering efficiency). Typically, 100 to 150 meter distance between the wells is used; this makes this system suited for buildings with a relative large lot.

Another aquifer system design is a recirculation system; this is a more simple design in which only one well is used for extraction and the other for injection. The temperature of the well is more or less fixed on a temperature of 10°C because hot water is injected in the summer and cold water in the winter.

The third type of system is the single well system (‘mono-source’) in which the hot and the cold well are separated vertically. The two wells are usually separated by an impermeable layer.

A potential problem for aquifers systems is potential clogging of the wells. If the permeability of the wells declines, the required pumping energy and the pressure increase, leading to higher electrical energy use. Monitoring and maintenance of aquifer systems is very important because they can prevent thermal short circuits and clogging.

In the Netherlands aquifer systems usually have a depth between 20 and 200 meters. Aquifer systems are suitable for large offices, residential areas (30 to 50 dwellings) and industrial areas. ATES technology is a mature technique that is applicable (profitable) without any subsidies. Currently aquifer systems are applied in offices (utility buildings) often, since a heating and cooling demand exists. The current PBP of aquifers systems for office buildings is between 3 and 7 years. Presently in the residential sector, heating is the primary need, while cooling demand is low (almost non-existing); therefore ATES is not interesting. However, it is expected that heating demand will decrease (and cooling demand increase), because newly built houses will be insulated better and have better air tightening. This makes aquifers systems an interesting option for the residential sector. [107]

Deep Geothermal systems

Geothermal heat extraction systems are extraction only systems. (Figure 40) When heat is extracted from the ground at a faster rate than the geothermal gradient can provide heat, the location of heat extraction is slowly cooled down over time. Due to the hot core and the mantle of the earth, a geothermal gradient exists which can be extracted using deep geothermal systems. In the top of the earth crust in the Netherlands an average geothermal gradient of 30°C per kilometre is found, corresponding to an energy flux to the surface of 0.063W/m^2. [91] Figure 54 and Figure 56 in Appendix VI show the potential for deep geothermal heat in the Netherlands at depths of 5500 and 7500 meter.

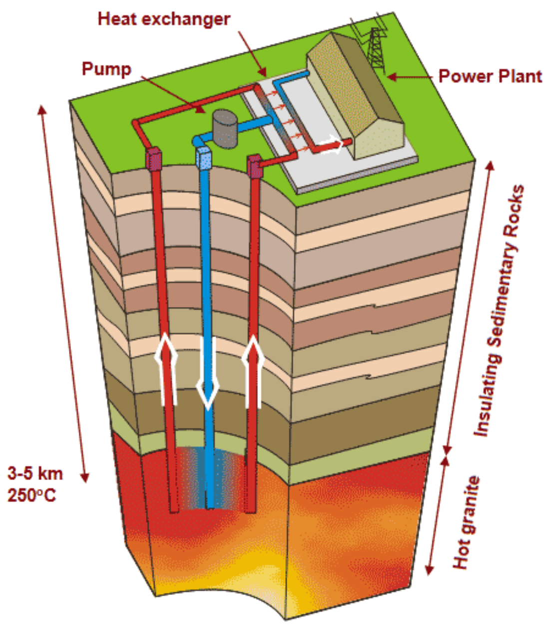


Figure 40: Deep geothermal system. [108]

Systems providing space heating, also called direct use systems, can directly utilize the low temperature heat from the wells for example district heating. The temperature level required by the application and the local geothermal gradient together determine the required depth of the well; for domestic heating applications this is typically in the order of 2 to 5 km. [91]
An important practical problem is the economic risk of deep geothermal. The local heat potential (permeability that is sufficiently high to extract water) can only be determined after a deep and costly well has been drilled. A typical drilling cost is in the order of 1-2 million Euros per kilometre. Another important aspect of deep geothermal systems is that geothermal extraction leads to depletion in the long run. [91]
In the Netherlands existing projects with depths of 1.5 to 3 km are in use, mainly for heating greenhouses but also applicable for residential heating. Drillings till 4 km depth are currently in preparation. The current ambition of the Dutch government is to provide 12% of the heat demand in the Netherland by geothermal heat by 2020. To realise this goal, 70 projects (both for greenhouses and residential districts) will be provided with geothermal heat. [109]

Combined Heat and Power

CHP systems are interesting for nZEBs because they produce heat and electricity at the same time, creating a higher overall efficiency compared to separate production. The efficiency cycle of a CHP unit compared to separate production is shown in Figure 41. CHP systems are usually driven by gas engines which propels a generator or a Stirling engine. Heat produced by the gas engine and exhaust fumes are used for heating purposes.

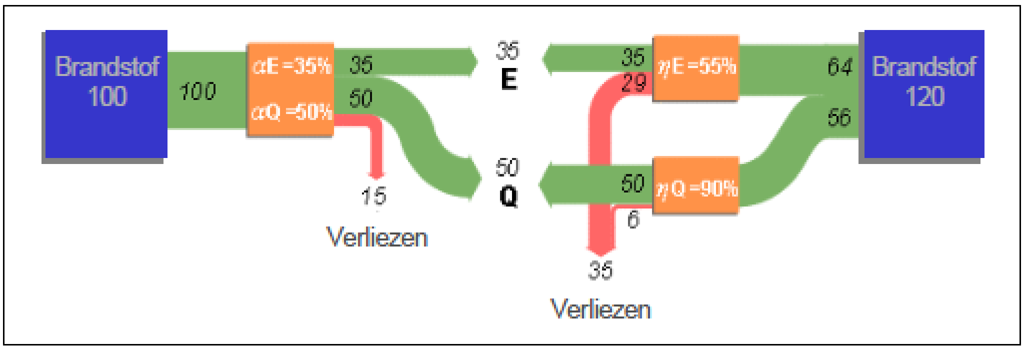


Figure 41: Efficiency cycle for electricity and heat production of CHP and separate production. [110]

CHP installations are interesting when a constant heat demand is required and electricity can be utilized directly. It can also be used as emergency power equipment; therefore CHP systems are applied more often in utility buildings, healthcare institutions or sports facilities. The payback periods of CHP installations are usually between 5 and 10 years.
In the Netherlands CHP is mainly used in greenhouses because of the constant demand for heat and electricity. Electricity that is not used is returned back to the grid. Since the electricity is fed into the local grid, losses compared to decentralized power plants are smaller. [111]
It should be noted that CHP is only sustainable when green gas (chapter 3.1.1) is used. With the current gas network infrastructure in the Netherlands and the increasing green gas projects, there is potential for CHP systems.

Solar collector
Solar collector systems are very interesting for nZEB since they can be applied in combination with many other others heating and hot tap water systems. The principle of solar collectors is based on harvesting radiation energy and converting it with a heat exchanger. Solar collectors are a low cost proven technology which has good potential in the residential sector and utility buildings with large roof combined with high considerable demand (swimming pool, sport facilities). Since there are so many possibilities with solar collectors, three most promising options will be discussed. The second and third options make use of an integrated solar roof. [113]

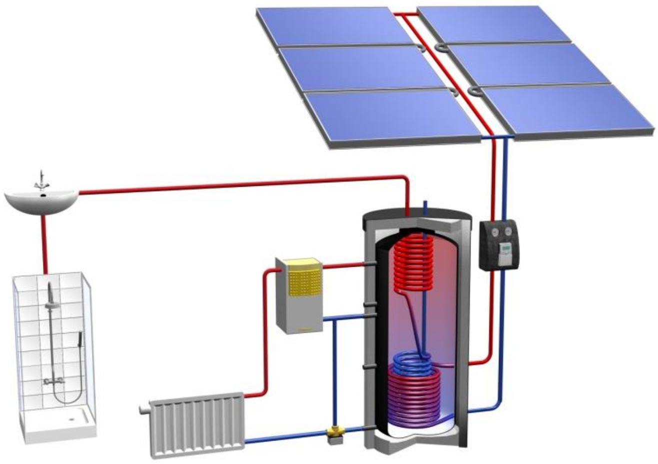


Figure 42: Solar collector with combi tank. [112]

- *Solar collector combined with a combi tank*; this system provides heating and hot tap water from one boiler. (Figure 42) Heat is primarily provided by the solar collector, additional heat is provided by a gas burner or electric unit. The water in lower part of the combi tank has a lower temperature and is suited for low temperature (floor) heating. In the upper part of the tank higher temperatures exists which can be used for tap water. Both heating water and hot tap water are separate with the boiler water because of legionella prevention.
- *Solar thermal roof combined with a GSHP*; the solar collector is connected to the GSHP system with a heat exchanger. The systems can be connected in series (reducing the size of the ground source heat exchangers, smaller investment) or parallel (resulting in a higher overall yield, lower overall cost).
- *Solar thermal roof with an aquifer system*; the solar collector is connected to the aquifer system with a heat exchanger. The same advantages/disadvantage as the previous system applies for a series or parallel connection.

Figure 43 shows the annual yield of a combined solar thermal roof with a GSHP (closed) system and an ATES (open) system, for a calculation of a terraced house reference building in the Netherlands. The different shades of green show the minimal and maximum performance of the systems. It can be seen that the aquifer system combined with a parallel connected solar collector has the highest annual yield. [113]

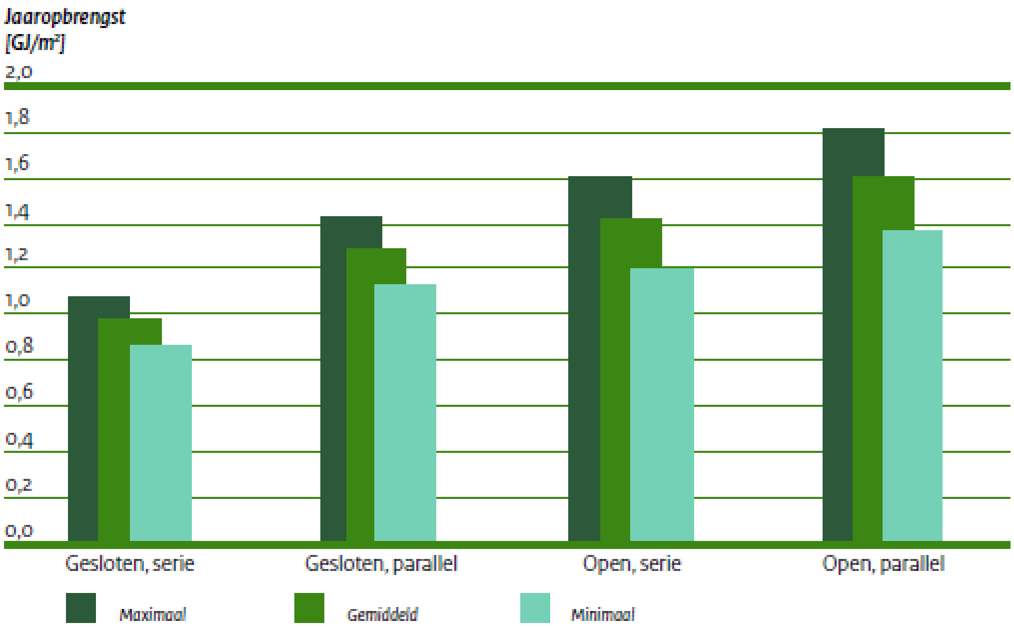


Figure 43: Annual yield of a combined solar thermal roof system per square meter. [113]

Photovoltaic's (PV)

PV technologies are mostly applied in the build environment as PV panels, however new combined and integrated techniques are also becoming available. In this part only standard (only electric) PV panels will be discussed.

Currently an increasing number of new buildings are fitted with (integrated) PV panels and also retrofitted panels for existing buildings are coming up. Different types of mounting systems exist today such as sun tracking systems, however most panels are static (fixed) on sloped or flat roof.

It is expected the efficiency of solar cells keeps increasing; today average efficiencies of PV panels are about 15% and in the near future (2020) this is expected to go up to 20-25%. The applicability of PV technologies in the built environment (Table 30) keeps increasing in the coming years because PV cells will become considerable cheaper. [114]

Table 30: Application of PV technologies in the built environment in 2010 and 2015. [114]

PMC	PV technologies							Year
	Si-wafer	Thin-Si	Thin-Cigs	Thin-CdTe	Thin-OPV	Thin-DSC	III-IV	
Renovation and new buildings (integration in roofs)	green	yellow	yellow	yellow	white	white	red	2010
	green	green	green	green	yellow	yellow	red	2015
New energy concepts for residential and utility buildings	green	yellow	yellow	yellow	white	white	red	2010
	green	green	green	green	yellow	yellow	red	2015
Infrastructure (lamp post, noise barrier)	green	green	green	green	white	white	red	2010
	green	green	green	green	yellow	yellow	red	2015
Energy producing greenhouses	green	green	green	green	yellow	yellow	red	2010
	green	green	green	green	green	green	red	2015
Industrial buildings	yellow	green	yellow	yellow	white	white	red	2010
	green	green	green	green	yellow	yellow	red	2015

green: Technology ready to be applied in 5 years	yellow: Technology almost applicable	red: Technology not suitable yet	white: Technology not distinctive or suitable yet

Rest heat
There is good potential for utilizing rest heat from industries in the Netherlands. From Figure 57 and Figure 58 (Appendix VI) can be seen that the many rest heat producers are situated near the large cities and rivers of the Netherlands. Rest heat is commonly used for district heating and heating of greenhouses.
The National Heat Expertise centre has made a quick scan of rest heat available per province. They have determined that the rest heat potential in the Netherlands is about 100PJ of which 57 PJ can be utilized for residential heating. This is enough to provide 1.2 million households of heat. [115]
It is expected that future buildings will have smaller heat demand because of good insulation; this could have consequences for the financial feasibility of district heating projects. The technical and financial factors are influenced by the future EPC demand, but it is not known to which extent. IPO expects there is a role for rest heat in new building sites. [115]

Wind energy on national level
The Netherlands has great potential for wind energy onshore and offshore because of its location close to the North Sea. At the end of 2012 a total capacity of 2.4 GW wind energy was installed in the Netherlands. Only a small part is recovered offshore (0.25 GW) while the rest (2.15 GW) is produced onshore (Figure 44.a). For comparison; Germany and Denmark produce a total wind power of 31.3 GW and 4.2 GW, respectively. The total installed wind power in Europe is 109.6 GW. EU wind power installations for 2012 do not show significant negative impact of market, regulatory and political uncertainty across Europe since the beginning of 2011. The projected amount of installed wind energy capacity in 2020 is 230 GW according to EWA’s (European Windtunnel Association) scenarios and 213 GW according to the European Wind Energy Association (EWEA). [120]

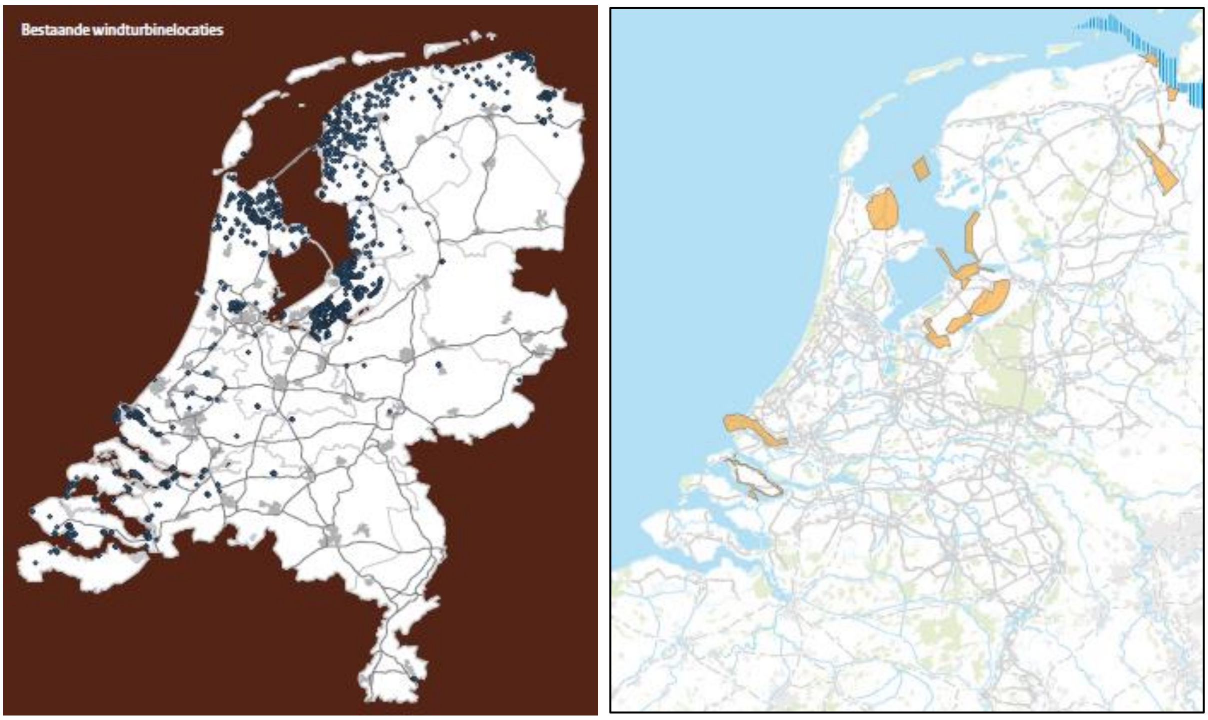


Figure 44: Wind turbine locations on land: a) existing locations and b) future (appointed) locations. [122][123]

The Dutch government has presented a structural vision for wind energy on land (SVWoL = StructuurVisie Windenergie op Land) which describes planning of wind energy production on Dutch territory. The government has the ambition to install a total of 6.0 GW in 2020 on land. Across the Netherlands 11 actual locations are appointed on land which are suited for large scale wind parks (capacity larger than 100 MW). These locations (shown in Figure 44.b) are mostly situated at the coastal areas and the province of Flevoland and Groningen. The wind conditions in the appointed areas are generally good and population density is low, furthermore landscape 'degradation' is limited because the areas mostly consist of ports and industrial areas or other large infrastructure (roads or canals). [121][123]

[B] Energy saving measures in development

The following energy saving measures in development will be discussed:

- Micro Combined Heat and Power (micro CHP)
- Small wind turbines
- CHP with biomass
- Photo Voltaic Thermal systems (PVT)
- Photo Voltaic Tubes
- Road collector

Micro Combined Heat and Power

In micro CHP heat and electricity are generated at small scale for residential use. As with (large) CHP the total efficiency is higher than for separate heat and electricity production.
Currently micro CHP systems are under development. An example of a micro CHP unit is shown in Picture 5. This type of model has a thermal capacity of 25kW, which is comparable with conventional high efficiency boilers. About 1kW of electricity can be produced with this unit. [116] The advantage of micro CHP systems is that the requirements are the same as a standard high efficiency boiler; little modifications are needed, which makes it interesting for retrofitting in existing buildings. It has to be noted that micro CHP systems are only renewable when green gas is used.

Picture 5: Micro CHP. [116]

Small wind turbines

In urban area small wind mills (Picture 6), also called urban wind turbines, have potential since they produce electricity close to the end user, reducing transport losses. Small wind turbines usually have a maximum height of 20 meters, generate electrical power of 1 to 25 kW and are suited to install on top of buildings. Two main types of small turbines exist [116]:

1. Horizontal wind axel turbines; these turbines resemble large scale turbines which have an axel turned towards the wind direction. (Picture 6)
2. Vertical axel wind turbines; the turbine axis is positioned perpendicular to the wind direction. The Savonius-type and the Darrieus-type are mostly applied vertical turbines.

Picture 6: Small wind turbine. [119]

Currently there is no national policy on small wind turbines in the Netherlands. Local initiatives are mainly supported by provinces or municipalities. For investors these wind turbines are still unattractive because of high costs; however the visibility is of great importance for the green image of commercial companies. [117]

A study on ten commercial small wind turbines with rated power from 2.5 kW to 200 kW in European countries (including the Netherlands) revealed that larger wind turbines require lower average wind speed to make them profitable (NPV > 0 and PBP within 15 years). Results showed that in the considered countries a set of conditions (installation location and wind turbine characteristics) affect profitability of small wind turbines most; national incentive schemes still play a crucial role. [118]

CHP with biomass

In the Netherlands there are already pilot projects in which biomass is used for district heating (Bio Energy Vallei discussed in chapter 3.1.3). Scientific research on CHP with biomass relevant for nZEBs is presented in this section.

In a study case on biomass resource potential in the province of Overijsel (in the east of the Netherlands) research was executed to determine the regions theoretical and technical potential. The biomass resource potential assessment indicates that 30.8 PJ of bio-energy is theoretically, while the technical biomass availability is only 2.7 PJ. This major loss is mainly due to the unavailability of agricultural biomass and the inefficient conversion of manure to bio-energy. The results indicate that Overijssel's potential bio-energy target is a share of 8.3%, which does not match with the desired policy target of 14%. Authors believe it is unlikely that the province's bio-energy ambition will be met with the current supply of biomass, in the absence of additional policy measures. [120]

A review has been carried out on the development of small- and micro-scale biomass-fuelled CHP systems. In this study comparisons have been made between different technologies such as biomass gasification and micro-turbine based biomass fuelled CHP systems. [125] The author of this study believe that the application of micro- or small- scale biomass fired CHP system has a great market potential in both UK and the rest of the world. They do however point out that the research and development on small-scale and micro-scale biomass-fuelled CHP systems is still in its infant stage. The relevant technologies in the current stage cannot meet the demands from different industrial sectors and research efforts are needed in order to provide a next generation of stand-alone small scale and micro-scale biomass fuelled CHP systems.

In 2003 a study was carried out on the possibilities of residential micro CHP systems. The application of micro cogeneration (< $15kW_e$) to residential and light commercial applications users was investigated. Energy saving and the environmental benefits of a micro-scale and on-site cogeneration were positive, however the technological obstacles still remained because systems with low price and easy-to-use operation for residential end-users was still being under development at the time. [126]

New promising biomass CHP technology, such as combined direct-biogas solid oxide fuel cell (SOFC) with a micro gas turbine (MGT) system, offers great potential as a green decentralized combined heat and power (CHP) system. [127] Further research and improvements on these systems is still required.

Photo Voltaic Thermal systems

A PVT system produces electrical energy as well as thermal energy. Two types of systems exist [128]:

- *PVT panels*; used primarily for electricity production. (Figure 45) The PV cells are cooled by an integrated tube system, increasing efficiency compared to standard PV cells. Heat which is extracted from panels can be utilized in a solar combi tank.
- *PVT collectors*; used primarily for heat production for low temperature heating and hot tap water. The PVT collector delivers higher temperatures than the PVT panel, but has lower electricity yield.

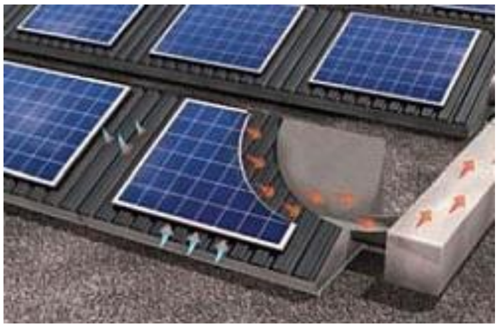


Figure 45: PVT panel. [128]

Total energy yield of PVT collectors is higher than two individual systems (PV panel and solar collector) and installations costs are lower. The overall costs of in integrated or individual system are comparable. PVT collectors can provide 30% to 60% of the annual tap water demand. An individual PVT system costs about €900 per square meter. (Juny 2010) [128]

In a study on the thermal and electrical performances of PVT solar hot water system in France, a comparison was made with a hybrid PVT collector (being part of a solar thermal system in a building) and a system with standard solar devices (solar collector and PV panels), shown in Figure 46. [129]

The results showed that in configuration of limited available space for solar collector area, the use of efficient PVT collectors in the building envelop can be more advantageous than standard PV and solar thermal components. Furthermore it is expected that the development of a new generation better performing PVT-collectors will provide advantages over separated solar collector and PV technologies. [129]

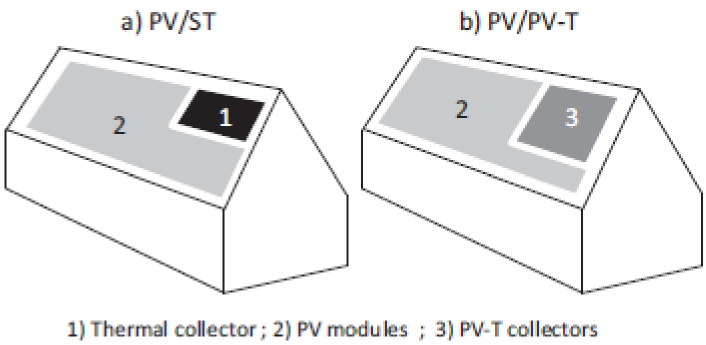


Figure 46: Side-by-side solar installations. a) system with solar thermal collector and PV panels b) system with PVT collector and PV panels. [129]

Photo Voltaic tubes

PV tube modules consist of rows of glass tubes with PV cells inside, as shown in Picture 7. The PV tubes have a higher efficiency compared to standard PV panels because of its cylindrical shape and the white roofing, which reflects sunlight. A typical module (Picture 8) is approximately 2 x 2 meter with a yield of 166 - 182 W/m^2. The modules can be applied on flat roofs, to which no additional constructive changes have to be made, because of its low weight (60 kg/m^2). This also makes it very interesting for existing buildings. [116]

Picture 7: Single PV tube. [130]

PV tube systems have high energy yield and low installation costs. The investment costs of are slightly higher than standard solar panels, however due to the higher yield the PV tubes produce electricity at a lower price per kWh. [116]

Picture 8: PV tube module. [116]

Road collectors

The Road Energy System is a combined technique in which an underground aquifer system is combined with an asphalt collector. The aquifer system consists of a hot and a cold well which obtain their energy form the asphalt collector. (Figure 47) In summer heat is collected and stored in the hot well and in winter cold is collected and stored in the cold well. As with a normal aquifer system heating and cooling is provided to buildings in the season when it is needed. The additional heat and cold stored in the aquifer layer is used to heat or cool the road. The Road Energy System requires a well-balanced control system. [131]

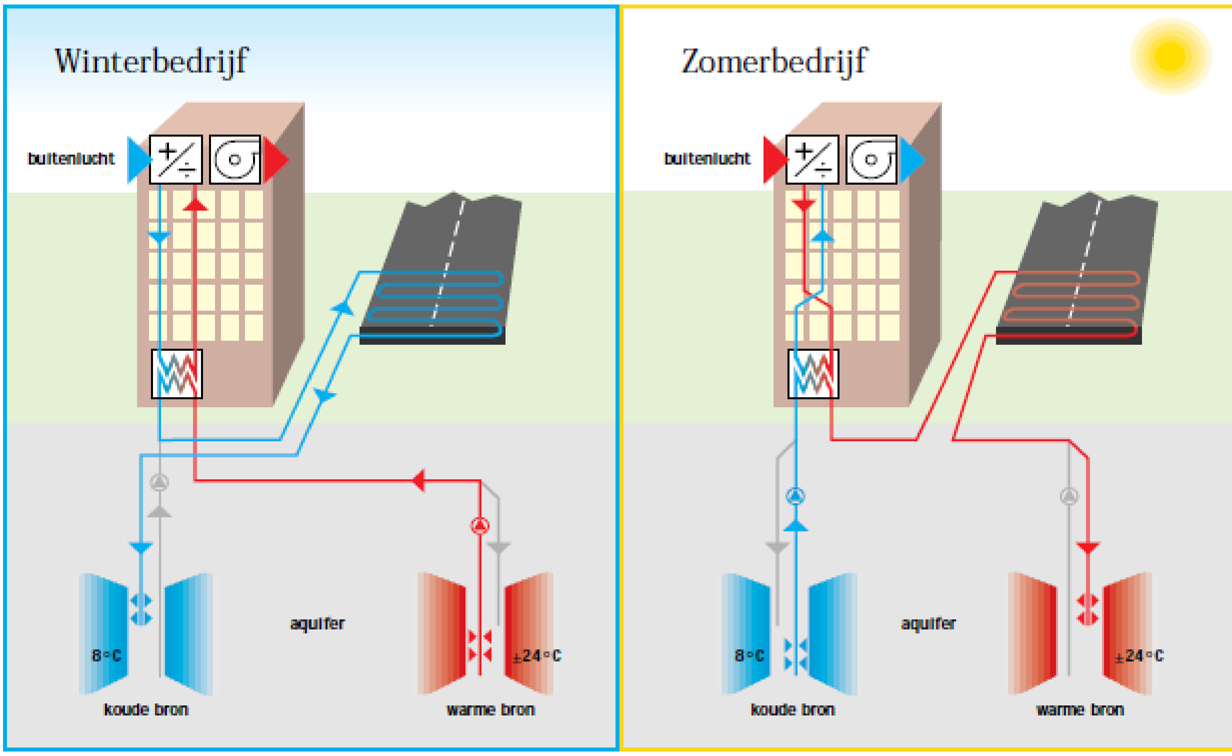


Figure 47: Road collector system in a) winter situation and b) summer situation. [131]

A road collector has many advantages with regard to the road surface. During winter the asphalt temperature can be kept above freezing point which improves road safety. The higher road temperature also improves evaporation of moist on the road. In summer the road is cooled which prevents deformation of the asphalt construction; this reduces tracks forming (rutting) therefore improving road safety. Furthermore fewer cracks will appear which makes the road more sustainable; less maintenance has to be performed leading reducing costs. Also the lifetime of the road and concrete road constructions is improved, since no salt has to be spread in winter reducing concrete corrosion. [131]

At present large and small scale projects have been equipped with this technology. Examples are: a group of 30 residential buildings in Waarland with a road collector surface of 635 m^2, an industrial area in Hoorn with a road collector surface of 3350 m^2, and a concrete overpass of the motorway A15 near Rotterdam with a road collector surface of 10,000 m^2. [132]

A literature review on asphalt solar collectors confirms good performance of asphalt collectors around the world (Switzerland, Japan, Netherlands, England, China Spain or United States) with different climate conditions. An important issue that has to be considered in road collectors is structural response of the system. Furthermore these collectors are not suited for road subjected to high traffic intensities or high traffic loads because the pipe system could be damaged due to a stress concentration. [133]
According to the study, asphalt solar collectors can be considered economically feasible from the initial investment point of view because two main reasons: the cost of the materials is cheaper than the materials used in a conventional solar collector and the asphalt surface can be used for other purposes. Asphalt surfaces perform as roads, playgrounds, bridges and at the same time they can be used to collect solar energy: this even reduces costs associated to the collector itself, while conventional solar collectors are used just for solar energy harvesting. On the contrary, the asphalt solar collectors' efficiency is clearly lower than the efficiency of conventional solar collectors because asphalt collectors are not specifically designed for solar energy harvesting. In addition to the initial investment, the operational cost of the whole system, including the heat pump device usually coupled with solar thermal collectors, must be carefully analysed and compared with conventional solar collectors to establish the economic feasibility of asphalt solar compared with other technologies. [133]

[C] Future energy saving techniques

Innovative future energy saving techniques that are still under developments but may be interesting for future nZEBs will be discussed here:

- Advanced control systems for local smart grids
- Innovative building materials
- Earth, Wind & Fire – Air-conditioning
- Baopt ventilation system

Many other interesting techniques for in the built environment can be found in the leaflet of Agency NL on innovative energy techniques for buildings. [116] New ideas for building installations and building materials are discussed which are promising for the future.

Advanced control systems for local smart grids
In nZEB design the electricity grid is seen as a virtual energy storage medium. A large amount of energy is exchanged with the grid to fulfil the yearly zero balance. The grid however has limited hosting capacity and can only accept limited spread of such buildings.
A study has been investigating the flexibility of nZEB designs with heat pump and PV application, since current market trend show these types of energy source will be applied most. Two different hydraulic configurations with the heat pump with thermal energy storage and four different control strategies where analysed. [134]
Results shows that with a proper control: self-consumption (when energy produced and consumed on-site) of the building could be improved by almost 40%. Hours of peak exchanges with the grid could be reduced by 30%. However, it was observed that the objectives are mostly contradictory: optimizing one objective degrades the other. Overall, significant flexibility in Net-ZEBs was found achievable if a proper control is in place. [134]

Innovative building materials

To further improve building performance building innovative building materials are developed to reduce primary energy consumption. Different interesting future materials will be discussed here.

Vacuum Insulation Panels *(VIP)*: these panels consist of a core material (which is placed inside the vacuum panel) of much lower thickness with the same thermal performance. The low weights of these panels make them interesting for light construction buildings. Some disadvantages of VIPs are that they cannot be cut on-site, it is fragile (can easily be damaged) and thermal bridged may occur when not installed correctly. [135]

Phase Changing Material (PCM) insulation: these materials use chemical bonds to store or release heat, reducing energy consumption. PCMs are often utilized as microcapsules, often mixed to mortars, which can be used in wall and ceiling construction. PCMs allows for a reduction of 4˚C in the daytime maximum room temperature, which reduces cooling need considerably. PCM could be interesting for the future but this technology is still far from mature. [135]

Cool roofing materials: these materials are defined by a high solar reflectance and high infrared emittance. Roof surface temperatures can be reduced significantly by replacing dark coloured materials with materials of the same colour containing near infrared reflecting pigments. Thermal performance of buildings can be improved considerably: reduced cooling loads up to 40% have been reported, however heating load also increased by 10%. Future development of these materials focuses towards dynamical optical characteristics, using the good qualities when needed. [135]

Translucent concrete: is created by mixed normal concrete with glass fibre optical strands, making up only 4% of the mixture. (Picture 10) The blocks have similar load bearing capacities as normal concrete could be interesting in urban area where many concrete structures are found. [136]

Picture 10: Translucent concrete. [136]

Textile waste insulation material: the potential application of Woven Fabric Waste (WFW) and waste of this residue, named Woven Fabric Subwaste (WFS) as thermal insulation material has been studied. The thermal conductivity value of the WFW is similar to the values of standard insulation materials such as expanded polystyrene, extruded polystyrene and mineral wool. Applying WFW and WFS as a possible thermal insulation material seems to be a useful solution, reducing energy and costs for making new insulation materials. In order to make this product suitable for the market more research work is needed in order to define a commercial product that can be introduced in the air-box of double walls. [137]

Picture 9: a) Woven Fabric Waste (WFW) and b) Woven Fabric Subwaste (WFS) [137]

Earth, Wind & Fire – Air-conditioning

The Earth, Wind & Fire (EWF) Air-conditioning system (Figure 48) is a device that uses renewable energy sources such as wind and solar radiation for the operation of a hybrid ventilation system. The EWF system is being developed for urban areas and could be applied on middle sized (minimal 4 stories) buildings. [138]

In a hybrid ventilation system the EWF system can be used to extract exhaust air with the use of a solar chimney (Figure 48, right channel). The solar chimney is featured with glass providing high transmittance and an absorber plate retaining the heat in the chimney. Heat collected in the chimney causes a draft (due to the difference in density of hot and cold air) which is used for ventilation, and can be used for building heating or underground storage. A climate cascade (Figure 48, left channel) is used for conditioning incoming air. Small water droplets are sprayed in this vertical shaft to cool the air in the summer and heat it in the winter. Hot and cold water used in this system is used from a heat and cold storage system. In order to improve the natural draft of the solar chimney and the climate cascade, a venture roof is used to enhance the positive and negative pressure. [138]

The EWF system seems promising, since only little amount of energy is required for the functioning of this system. It should be noted however that it is still in research phase: currently CFD modulations are being executed and many hurdles have to be overcome. It is difficult to create a continuous supply/exhaust system which is dependent on solar radiation.

Experts also issue that the majority of the Dutch built environment is not suited for EWF hybrid type of ventilation systems because they do not function properly (no guarantee for a good indoor climate) and Dutch architecture does not lend itself for this system. [139] Furthermore these experts dispute the financial advantages compared to a regular system, which is much less expansive. The main withdraw of the EWF system is the adiabatic cooling system, which is ‘an almost impossible installation concept in conventional Dutch buildings’.

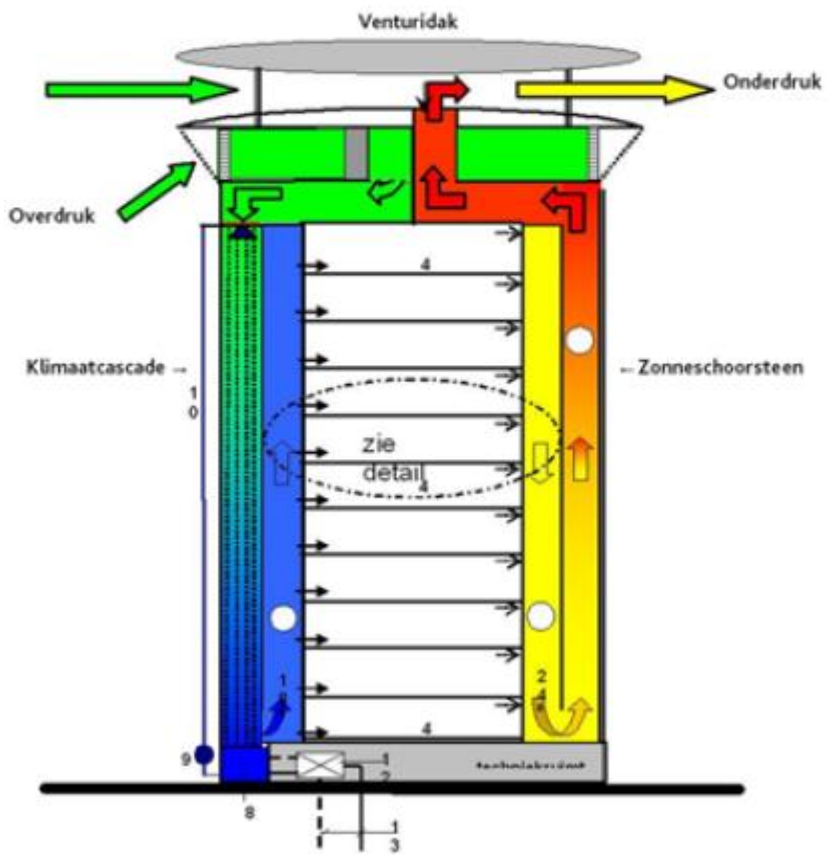


Figure 48: Earth, Wind & Fire Air-conditioning principle. [138]

Baopt ventilation system

An innovative way of ventilating a building is with the Baopt ventilation system. The technique uses a patented dispersing ventilation method based on resonance of air. This enables the air to be spread evenly over the room as shown in Figure 49, resulting in a constant and optimal indoor temperature. Conventional ventilation technique can cause air layers with different temperatures (stratification), which results in discomfort (e.g. drafts, downdrafts by windows). Stratification does not occur in the Baopt ventilation systems. Because of the diffusion process no large fans or large air flows are needed in the Baopt system. An additional advantage of this technique is that a small layer (few millimetres) of stagnant air forms alongside walls, this creates an isolating effect. Because of this effect no downdrafts by windows takes place and no condense is formed (e.g. indoor pools). [140]

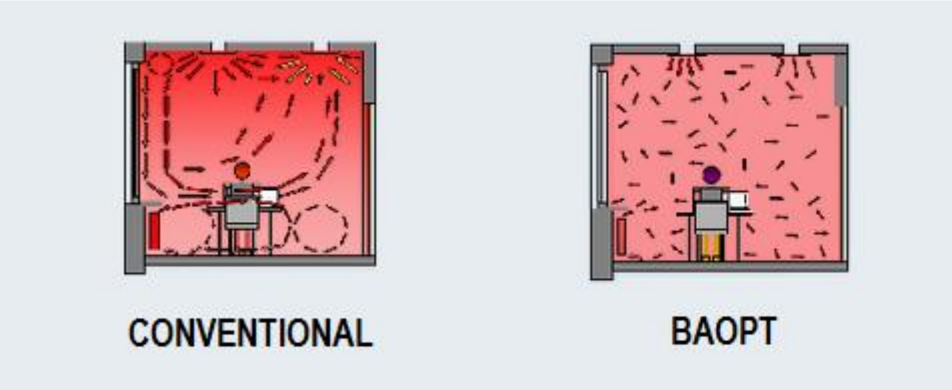


Figure 49: Conventional ventilation system and the Baopt ventilation system.

Baopt is a new technology which is already applied in small buildings such as schools and small centres, but also in airports and greenhouses. Examples projects are: Cologne-Bonn airport, the University of Frankfurt and Golden Hall in Vienna (concert room). The ventilation system is sensor driven; air is renewed when it is actually necessary, no standard ventilation rate is used. Considerable less energy is needed to disperse the air: energy saving compared to a conventional HVAC system can be up to 25% and 40% for newly built and renovated buildings, respectively. A typical Baopt project usually has a PBP between 1 and 5 years. [140]

The savings mentioned earlier have not been scientifically proven yet, since the company which owns the Baopt technology does not want to give away the working principle. It therefore will take some time to objectively determine the energy savings, e.g. compared to other systems. Only than it is possible to say which energy saving amount can be assigned to the Baopt system.

Appendix VI Sustainable resources in the Netherlands

Biomass projects

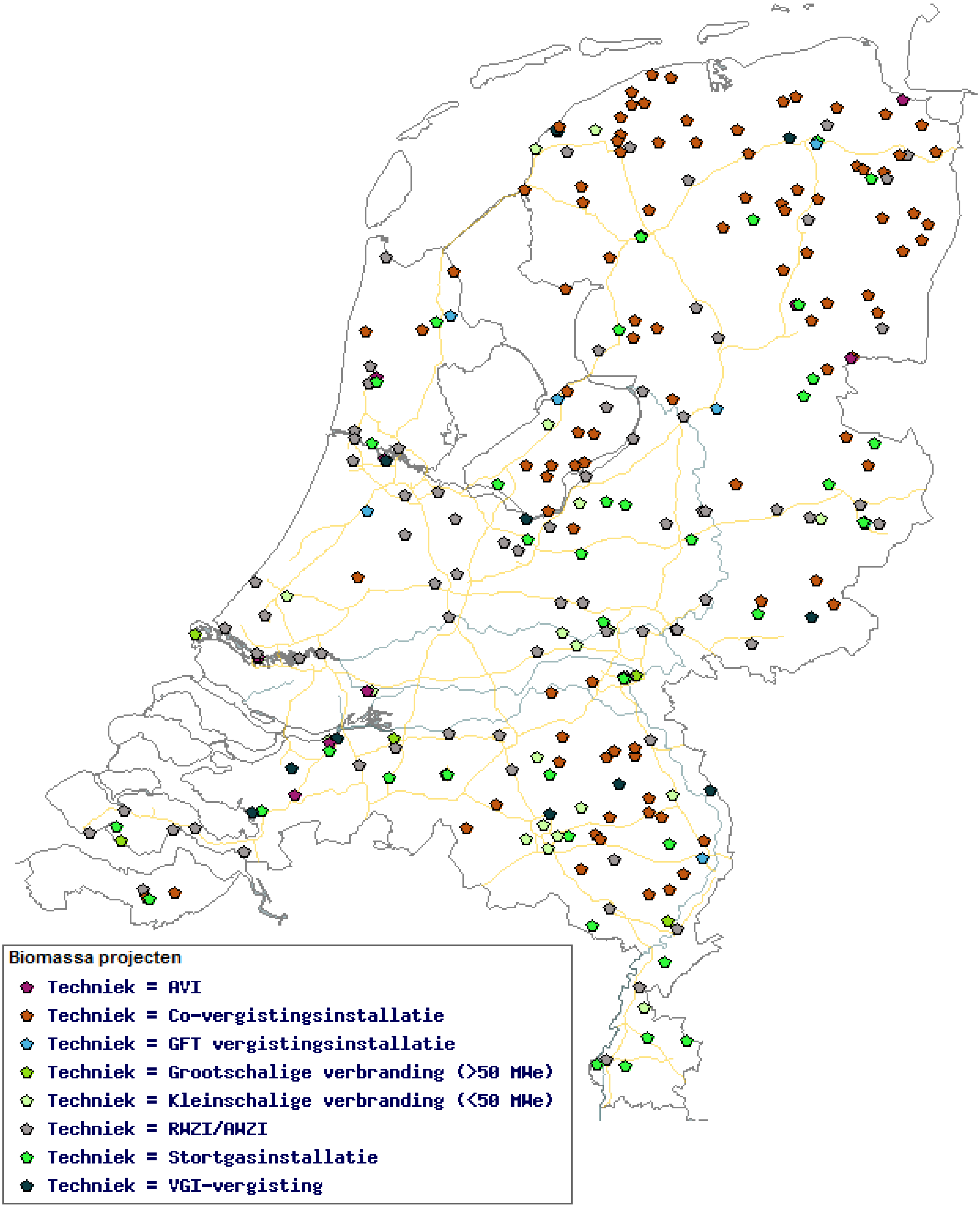


Figure 50: Biomass projects in the Netherlands. [141]

Ground Source Heat Pump - heat potential
Vertical system

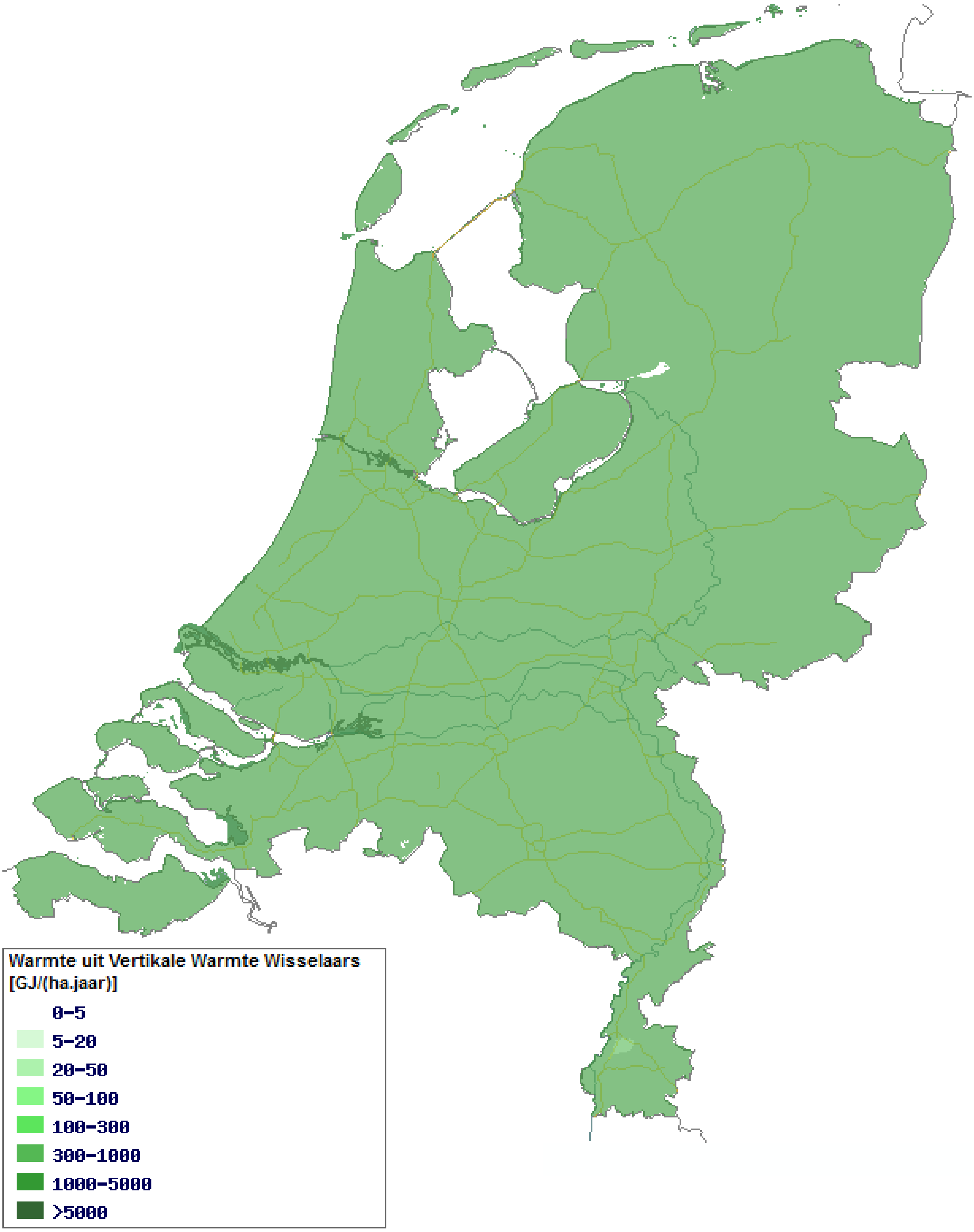


Figure 51: Ground Source Heat Pump (GSHP) heat potential in the Netherlands. [141]

Ground Source Heat Pump - cold potential
Vertical system

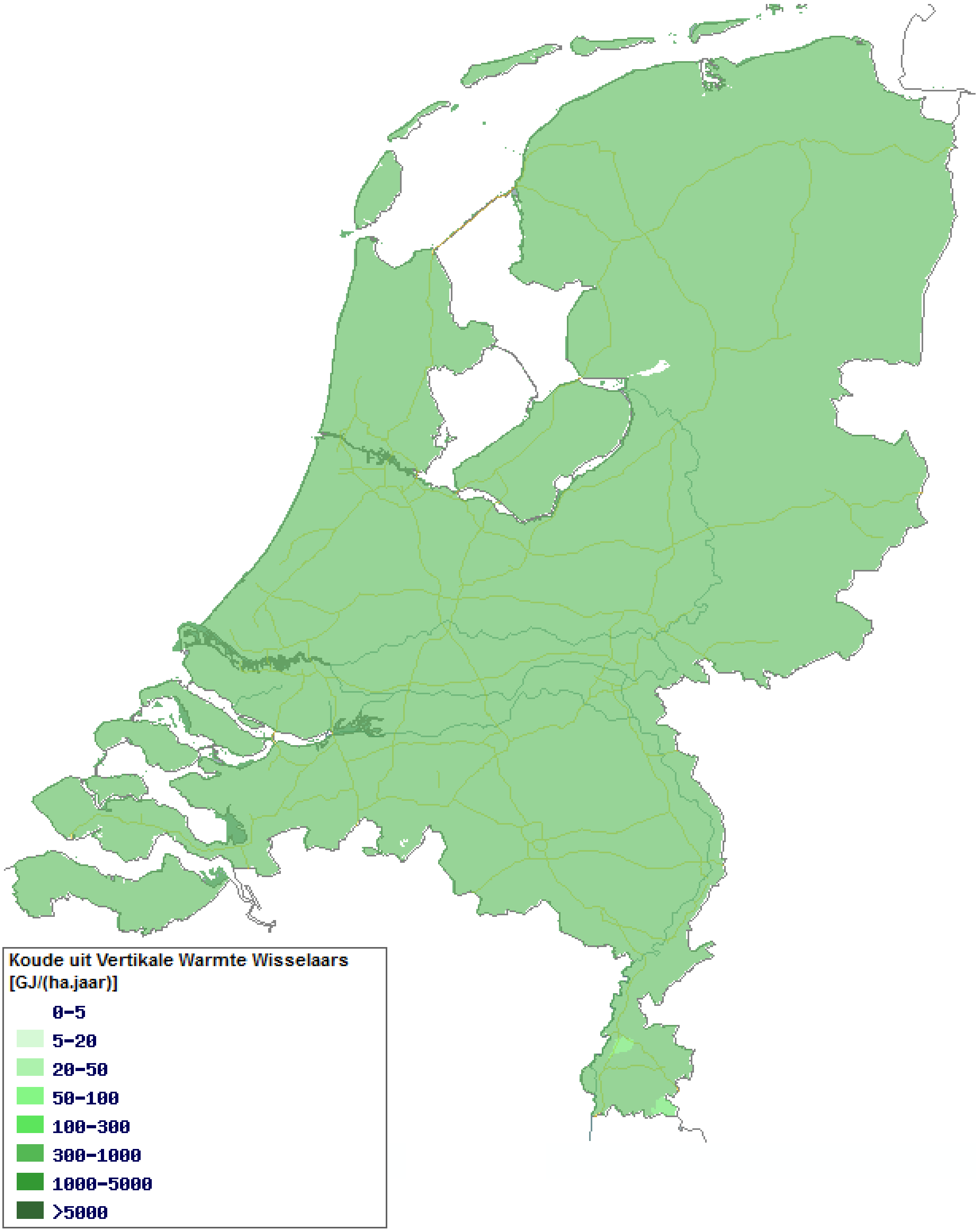


Figure 52: Ground Source Heat Pump (GSHP) cold potential in the Netherlands. [141]

Earth heat from aquifer systems potential
Depth: 1500-4000 meter

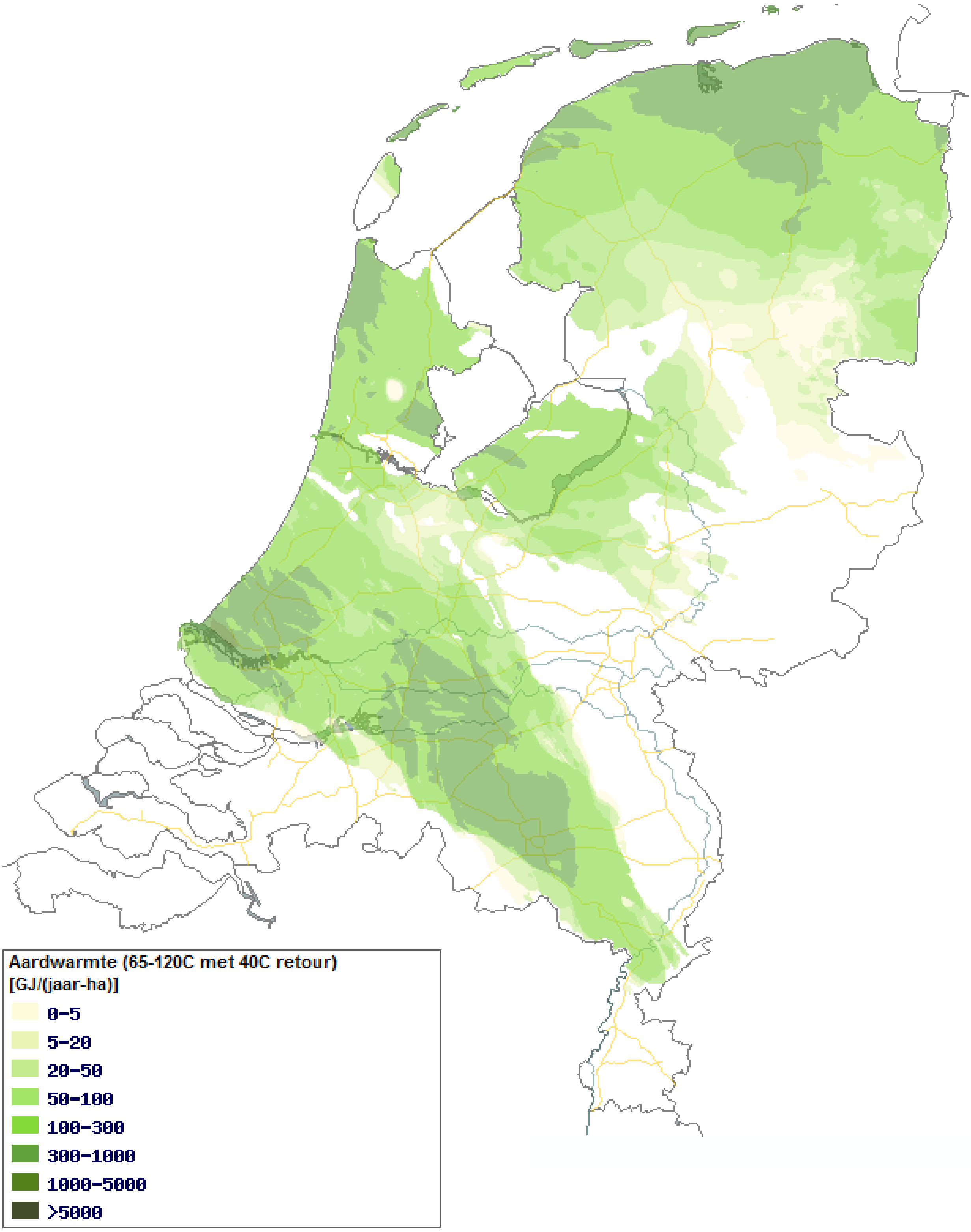


Figure 53: Earth heat from aquifer systems potential in the Netherlands. [141]

Deep geothermal heat potential
Depth: 5500 meter
Figure 54: Deep geothermal heat potential at 5500 meter depth in the Netherlands. [141]

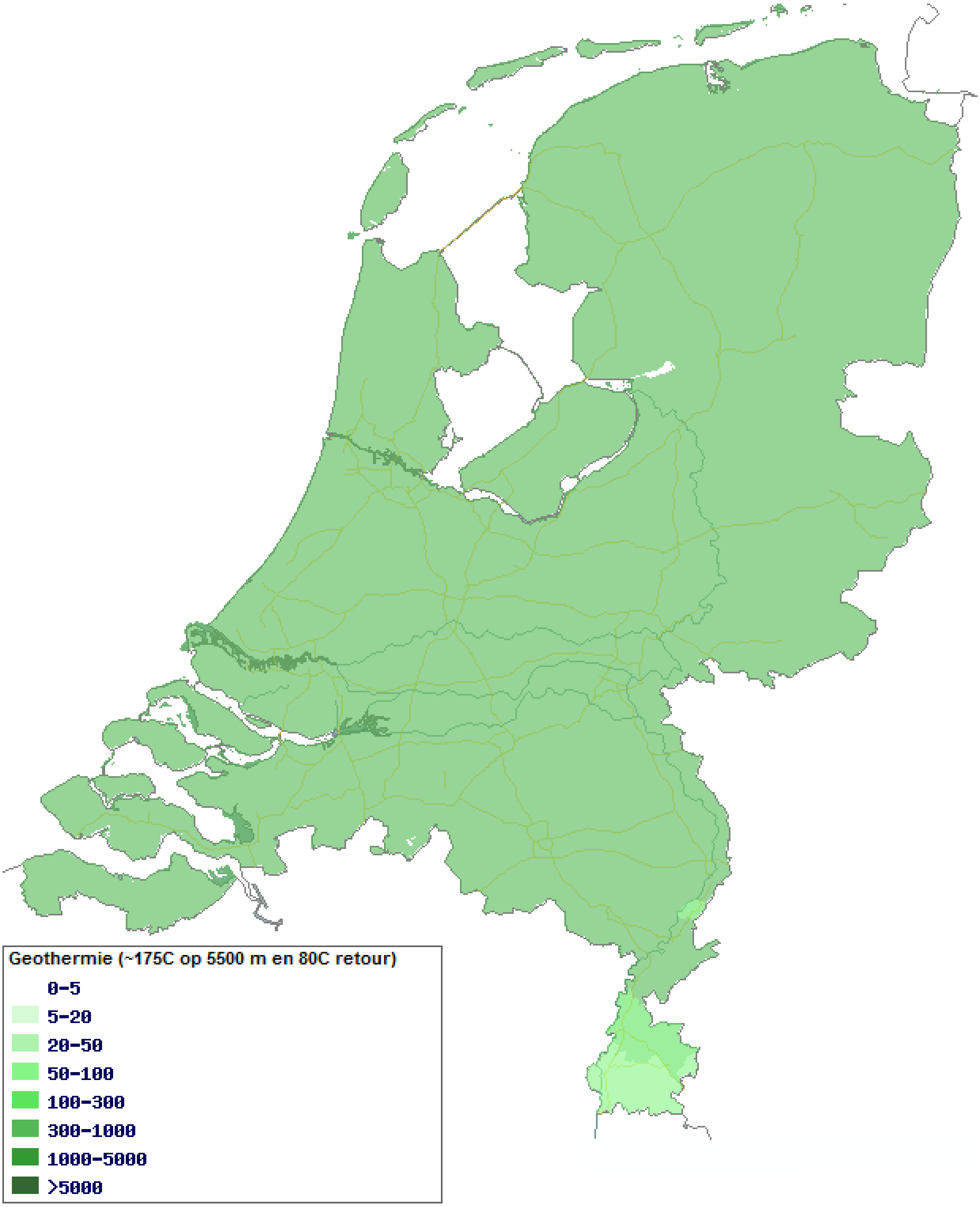


Figure 55: Deep geothermal heat potential at 5500 meter depth in the Netherlands. [141]

Deep geothermal heat potential
Depth 7500 meter

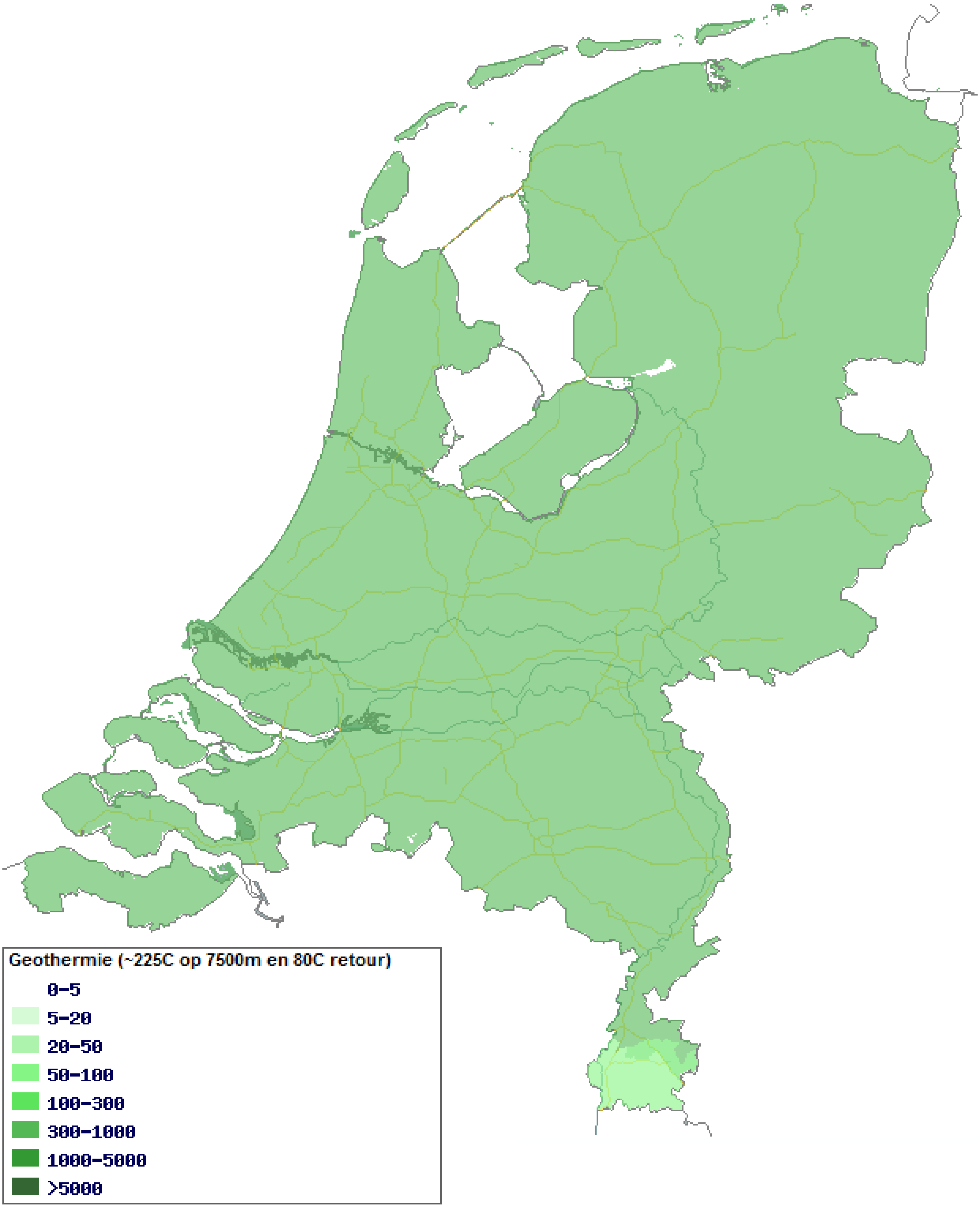


Figure 56: Deep geothermal heat potential at 7500 meter depth in the Netherlands. [141]

Rest heat - low temperature
Temperature: <120°C

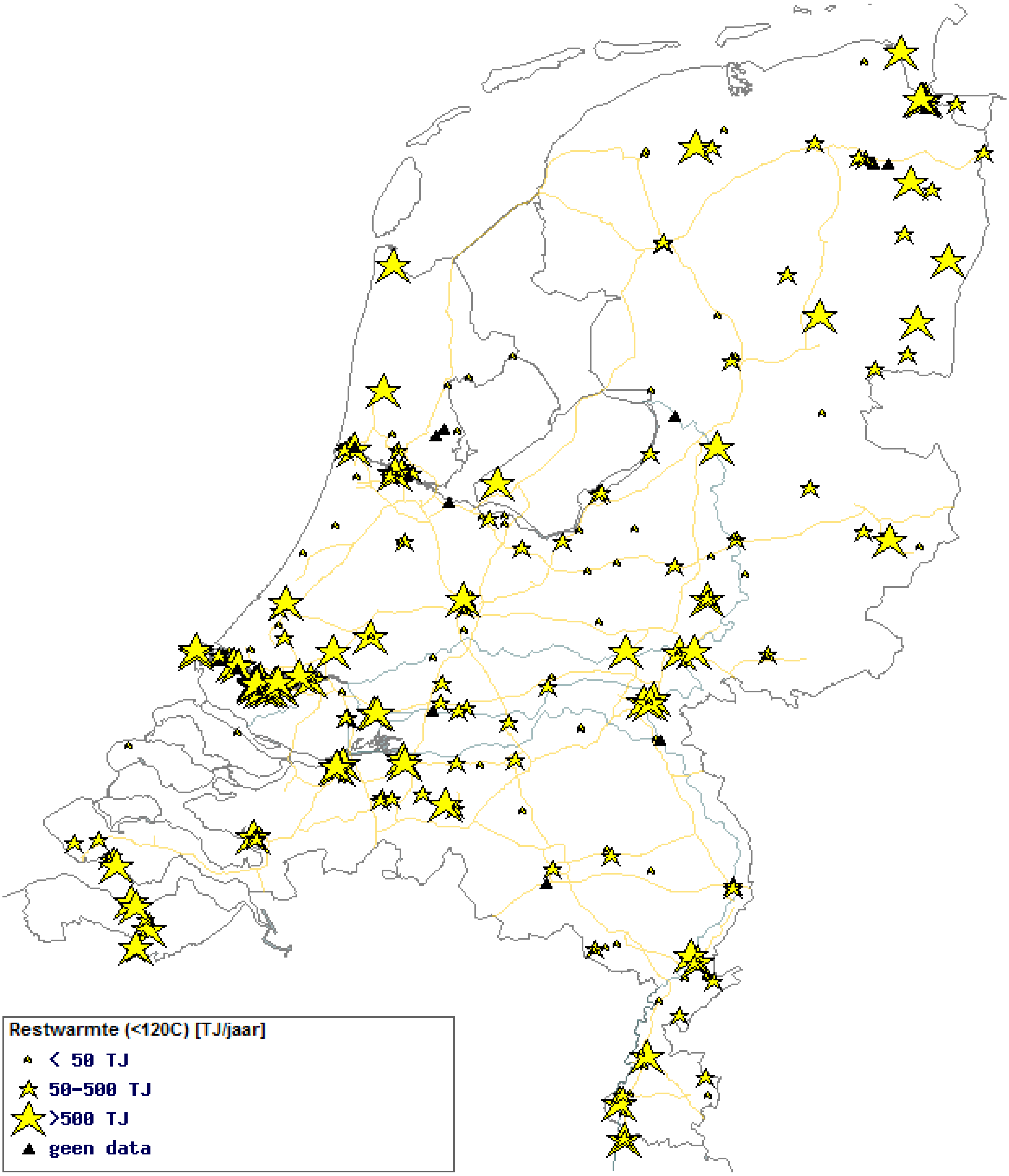


Figure 57: Rest heat at low temperature (120°C) in the Netherlands. [141]

Rest heat - high temperature
Temperature: 120-200°C

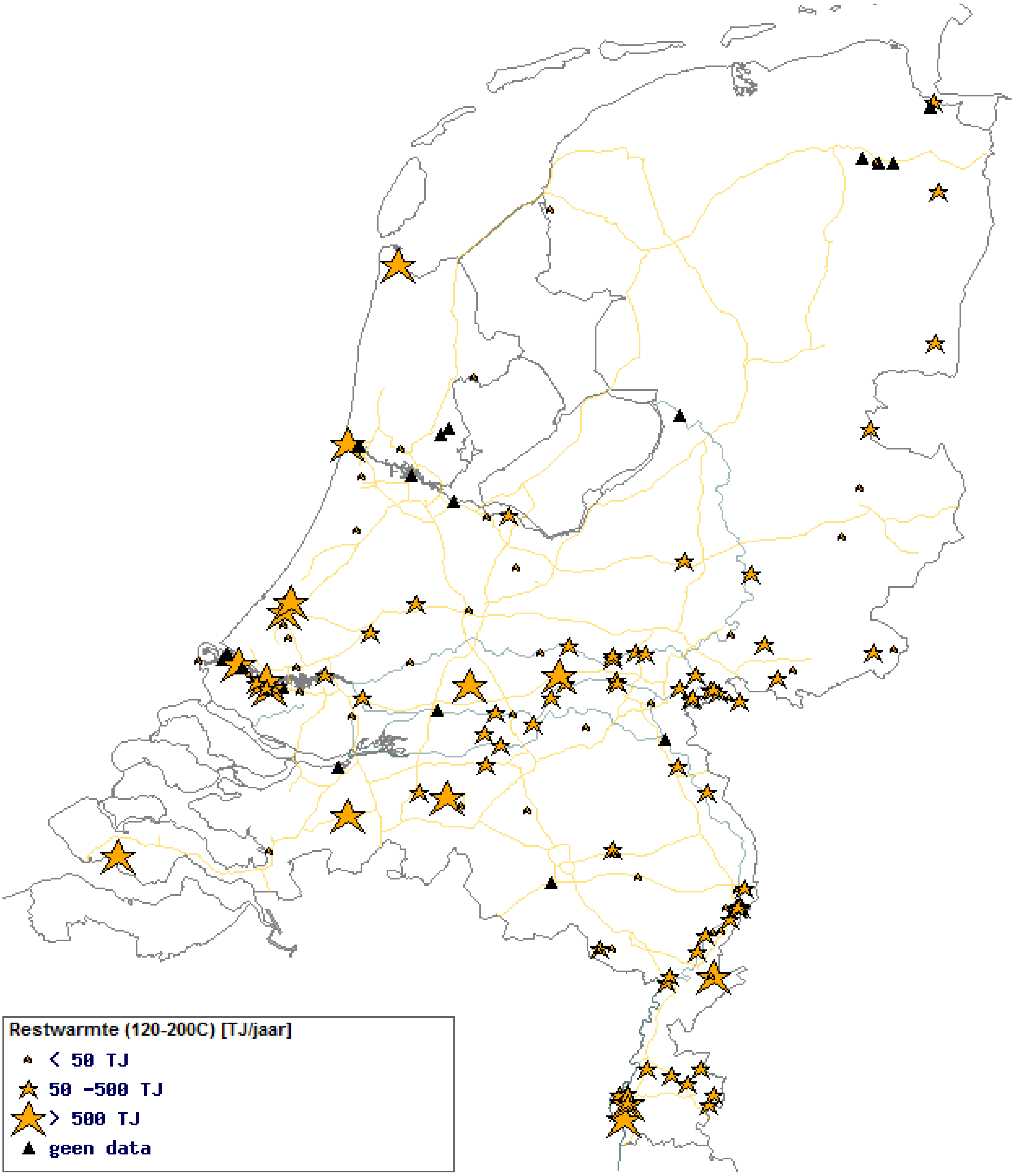


Figure 58: Rest heat at high temperature (120-200°C) in the Netherlands. [141]

Appendix VII Energy infrastructure Rotterdam

This appendix describes current en future plans and projects relating to energy infrastructure and nZEBs within the municipality of Rotterdam.

RCI

The Rotterdam Climate Initiative (RCI) is a climate program supported by the municipality of Rotterdam, Port of Rotterdam, Deltalings and DCMR Milieudienst Rijnmond. RCI has realized the 'RCI Actionplan Energy' [142] in December 2013 where action plans for the period 2014-2018 and future requirements for climate ambitions in 2025 are discussed. Two focus points that concern energy infrastructure and nZEBs are discussed below. [142]

- One of the RCI future focus point is the '*Deltaplan Energy-Infrastructure*'. This plan focuses on 'common carrier' infrastructure (consisting of rest heat, rest steam and CO_2), from the harbour and industry complex to the urban area and greenhouses. The goal is to realize an energy reduction of 20 PJ by 2020 and an additional 12 PJ for future realization. In 2013 the first phase of the Botlek steam-network has been put into operation. A heat-network, providing heat for houses in Rotterdam, is in operation since the autumn of 2013.
  The Port of Rotterdam responds to current trends and opportunities in both the supply (industry) and the demand side to improve the transition towards renewable and cleaner energy. An example of this policy is the closure of the old STEG power plant (Centrale Galileïstraat) as driver for heat-network in the north Rotterdam.
- *Large scale energy reductions in the built environment* and small and medium businesses is another important focus point. The program 'Acceleration 010' ('versnelling 010') is an energy saving initiative focused on realization of existing buildings. The goal is to realize 10,000 energy saving dwellings by 2018 and 30,000 dwellings in 2025.
  An additional goal is to start collective sustainable energy projects in which solar energy techniques are implemented on a district scale. It is very important that 'standard solution packages' are deployed, so they can be implemented in all districts.

REAP methodology

The Rotterdam Energy Approach and Planning (REAP) describes a methodology based on the Trias Energetica. This methodology, also called New Stepped Strategy, adds an important intermediate step in the Trias Energetica (in between the reduction in consumption and the development of sustainable sources), and incorporates a waste products strategy (inspired by the Cradle-to-Cradle philosophy) [143]:

1. Reduce consumption (using intelligent and bio climate design)
2. Reuse waste energy streams
3. Use renewable energy sources and ensure that waste is reused as food
4. ~~Supply the remaining demand cleanly and efficiently~~

As can be seen, the New Stepped Strategy has a new second step that makes optimal use of waste streams (heat, water, material) not only for each individual building but also on a city wide scale.

This new method has been applied on generic scenarios on four different levels: city, district, neighbourhood/cluster and building. The scenarios describe different existing building or building clusters that will be renovated or extended and new buildings and clusters. REAP was also applied in a study case 'Hart van Zuid', an existing centre in the urban area of Rotterdam. [143]

From the report was concluded that the REAP-methodology is architecturally independent and allows for different solutions – and the associated different architectural expressions. After applying REAP to 'Hart van Zuid' project, calculations have shown that CO_2 neutral urban development within the built up area of an existing city region is possible.

Energy infrastructure project

Two examples of green infrastructure in Rotterdam:

- *Green façade* [144]; the parking garage at Westblaak has a green façade with ivy plants. The positive effect of ivy planted facades is reduction of particles matter in downtown Rotterdam. The green façade has the same effect as 200 mature grown threes. Other benefits are: CO_2 uptake of vehicles in the garage; a more diverse biodiversity in the centre; and reduction of the 'heat island' effect (by reducing irradiation to buildings). Furthermore the sewage has to process less rain water, since water is taken up by the plants.
- *Solar energy roof* [145]; Rotterdam has interesting solar projects and was therefore elected 'Solar City 2012'. Buildings with large roof surfaces such as the Oceanium of the Blijdorp Zoo and the sunroof of the new train station of Rotterdam contributes to sustainable energy targets. The train station has a total surface of 10,000 m^2 of solar cells incorporated in glass, providing electricity and transmitting light on the platforms.
  The municipality is also planning ahead to facilitate easier authorization procedures in order to encourage large-scale deployment (40,000 m^2) of solar panels on municipality buildings.

On December 13th 2013 the Municipality of Rotterdam, district of Hoek van Holland and City-Region of Rotterdam presented their plans for the Windpark Nieuwe Waterweg producing electrical energy for 30,000 homes. The wind park with a total capacity of 109 GWh will be in operation in 2015 and is situated alongside the Nieuwe Waterweg between Hoek van Holland and Maassluis. (Figure 59) The park consists of 7 turbines with a hub height of 119 meter and a rotor diameter of 112 meter. [146]

Figure 59: Locations of wind turbines alongside the Nieuwe Waterweg. [147]

Appendix VIII Building energy performance with ENORM

The EPC score and primary energy demand have been determined using the dGmR tool ENORM. This appendix describes the input values and PV design applied on the roof and façade of the nZEB office building scenarios (U_1, U_2, U_3).

The simulation settings used for the ENORM calculation can be found Table 31. Data from the reference buildings (Agency NL) and data of example nZEBs in the Netherlands has been used to determine these values.
The first rows in Table 31 show the EPC score and primary energy demand. U_2 has the best energy performance with a EPC of 0.14 and a primary energy demand of 15.4 kWh/(m²a).
The nominal power for heating and cooling where used to determine the size of the installation; these values were required to determine the cost of the heat pump and the wells.

Table 31: ENORM simulation settings for office buildings.

	Urban Area scenarios Office building			
	U_{ref}	U_1	U_2	U_3
EPC	0.70	0.20	0.14	0.15
Primary energy demand [kWh/(m²a)]	79.0	23.1	15.4	17.1
Construction				
Insulation R_c [m²K/W] - Wall - Roof - Floor	 5.0 5.0 5.0	 6.0 8.0 5.0		
Floor mass	High (> 400 kg/m²)	High (> 400 kg/m²)		
Window U [W/(m²K)] - Glass and frame - ZTA	 1.3 60%	 0.8 60%		
Installations				
Heating Cooling	Vertical GSHP with low temperature (30-35°C) floor heating	Vertical GSHP with low temperature (30-35°C) floor heating	ATES with low temperature (30-35°C) floor heating	ATES with Road Collector with low temperature (30-35°C) floor heating
Nominal power [kW] - Heating - Cooling	 29.1 75.5	 7.0 85.4	 7.0 85.4	 7.0 85.4
Hot tap water	Small electric boiler	Small electric boiler	Small electric boiler	Small electric boiler
Ventilation	Mechanical (balanced) with heat recovery (70%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)	Mechanical (balanced) with heat recovery (95%)
Lighting system	Efficient lighting system (8 W/m²)	Efficient lighting system (8 W/m²)	Efficient lighting system (8 W/m²)	Efficient lighting system (8 W/m²)
Humidification	Humidifier	Humidifier	Humidifier	Humidifier
Electricity generation	PV cells 170m² (roof)	PV cells 770m² (roof) 375m² (façade)	PV cells 770m² (roof) 375m² (façade)	PV cells 770m² (roof) 375m² (façade)

PV panels

Electricity generation by PV panels is provided on the roof and on the façade of the office building. This section shows how the PV panels are positioned on the building. Specifications of the PV panels used are shown in Table 32.

Table 32: PV panel specifications. [148]

Brand	Eging	
Cell type	polycrystalline	
Peak power, W_p	149	W/m^2
Energy yield	4500	kWh/a
Dimension (l x w x h)	1.69 x 0.99 x 0.035	m
Weight	18,6	Kg
Performance guarantee	90% for 10 years 80% for 25 year	-
Costs 5000WP package	6,889	€

Roof

The roof is completely covered with a total of 400 PV panels as shown in Figure 60. Small space is left to place a hatch and/or chimneys.

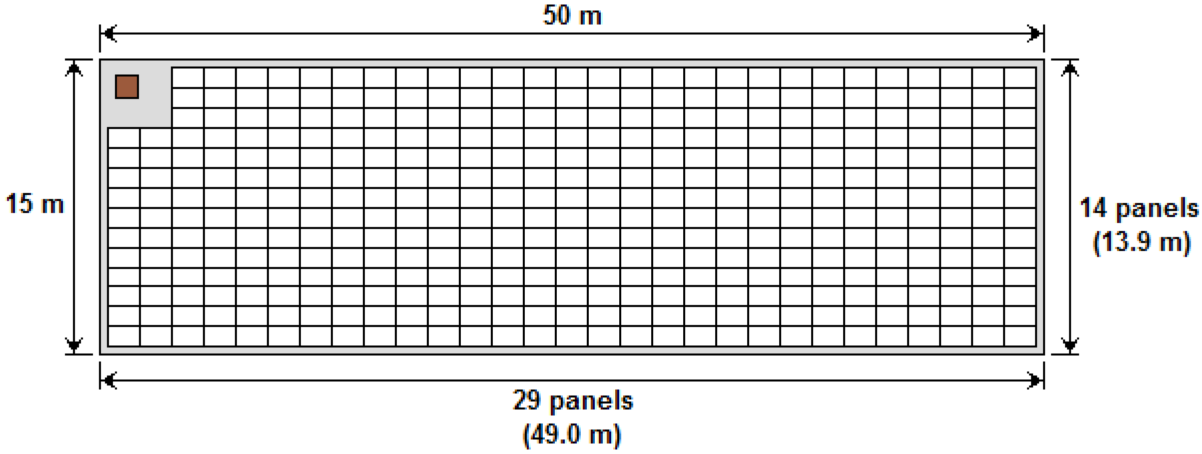


Figure 60: PV panels installed on the roof of the office building nZEB scenarios.

Façade

Currently several possibilities are available for PV integration in façade as shown in the Eneco headquarters (Picture 1) and Picture 11. Additional PV panels were required for the office building nZEB scenarios to obtain a sufficiently low EPC score. Several PV façade design options have been considered as showed in Figure 61.

Picture 11: Example PV facade of a small office building. [149]

Four design options have been compared to determine which solution results in the lowest EPC score and primary energy demand. All calculated values for different PV facade design options have been calculated for nZEB scenario U_1. The total energy demand calculated already includes 670 m² PV panels on the roof. For PV facade 2, 3 and 4 the shadow factor has been calculated according to NEN 7120. From Table 33 can be seen that PV façade 4 has the lowest EPC score and the lowest primary energy demand. This design option has been applied in the nZEB scenarios for office buildings.

It should be noted that the optimal angel at whom a PV panels generate the highest energy yield is smaller than the 45° (usually around 30°). However, the highest energy yield (according to ENORM) was obtained at an angle of 45°, so that angel has been applied.

Table 33: Comparison of four PV facade designs.

	Design options				
	PV facade 1	PV facade 2	PV facade 3	PV facade 4	
Number of panels					
Vertical [0°]	203	29	0	0	-
Sloping [45°]	0	150	200	224	-
Total	203	179	200	224	
PV surface					
Vertical (90°)	339.6	48.5	0	0	m²
Sloping (45°)	0	251.0	334.6	374.8	m²
Shadow factor* for sloped panels	1	0.9	0.9	0.9	-
ENORM results					
EPC	0.275	0.275	0.237	0.204	-
Primary energy demand	336,688	332,611	289,293	249,878	MJ/a
Costs					
Investment (20 panels and equipment)	€70,685	€66,501	€74,890	€84,294	€

* according to NEN 7120 chapter 21.3.1

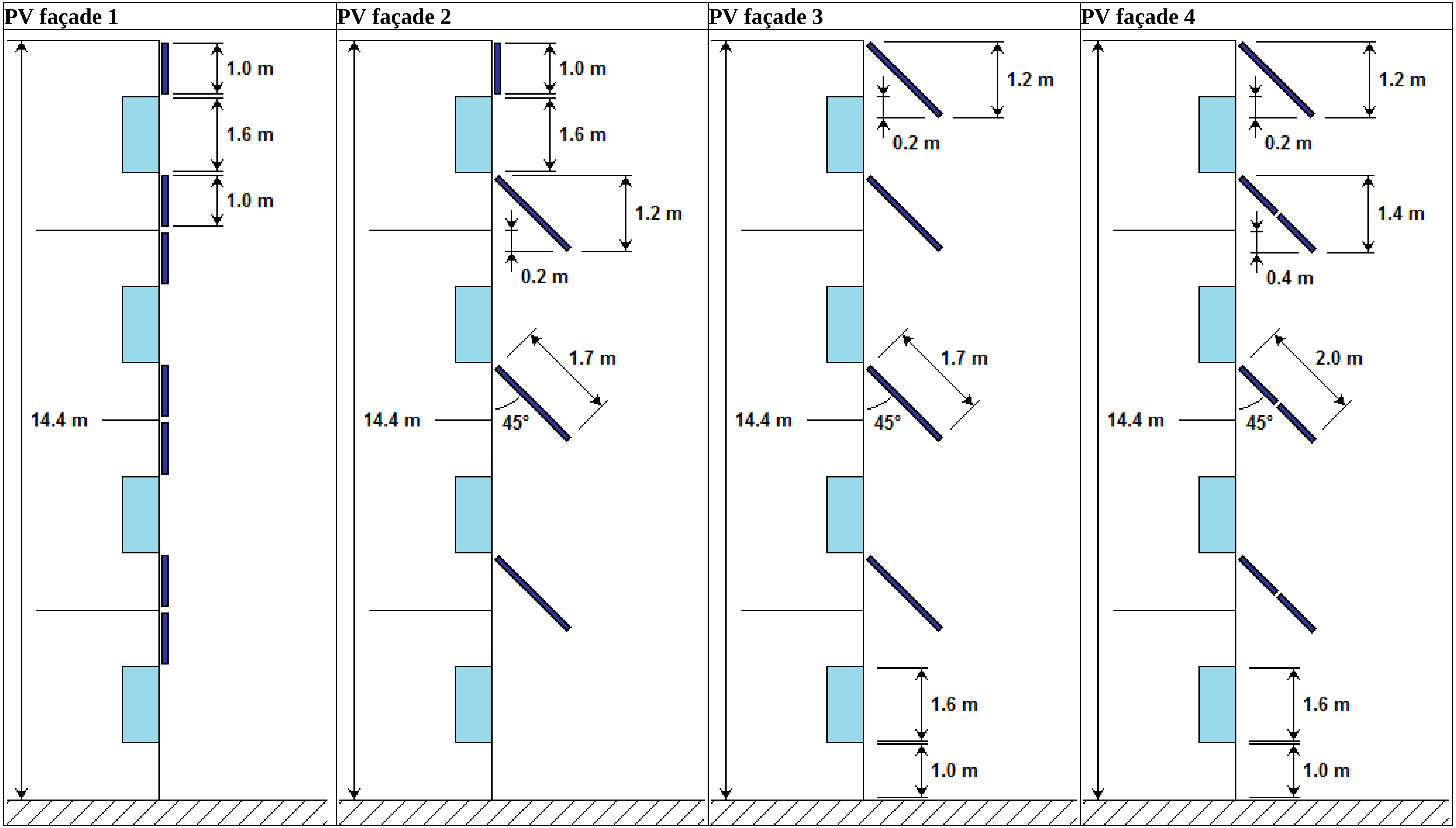


Figure 61: PV facade design options.

Appendix IX Underlying documents

Since the introduction of the EPBD in May 2010 new regulation and guidelines have been published in order to help MS define an nZEB definition. A framework for the cost optimality calculation method was supplied by the EU and used by dGmR and RHDHV for studies considering nZEB (energy saving measures) and cost optimality of reference buildings.
The following documents were underlying to this report for the path towards nZEB project.

European Commission: EU legislation and regulations
19 May 2010 – EPBD (Energy Performance on Buildings Directive) [5]
21 Mar 2012 – Regulations (supplementing EPBD) [6]
19 Apr 2012 – Guidelines (accompanying Regulations) [150]

CA (Concerted Action) EPBD
July 2011 – *Cost optimal levels for energy performance requirement* [151]: report for exchanging knowledge on cost optimal levels for energy requirements. The goal of this report is to merge knowhow and experience between MS.
May 2012 – *CT4-Cost-optimum Procedures, Implementation step-by-step* [152]: summary of CA EPBD meeting on cost optimality. CA EPBD is an activity which aims to foster exchange of information and experience among MS and participating countries with regard to the implementation of the specific community legislation and policy on the energy performance of buildings.

RGD (RijksGebouwenDienst)
3 Jan 2013 – Mail on nZEB vision: describes the motivation and approach of the DGMR report from March 2013 on cost optimality calculations.

dGmR
17 Nov 2009 – *Aanscherpingsstudie EPC-woningbouw 2011* [79]: study on the effects of lowering the building energy performance on newly built residential buildings in 2011 to EPC=0.6.
11 Mar 2013 – *Kostenoptimaliteit energieprestatie eisen Nederland* [80]: report on principles and results of calculations based on European cost optimality methods. This report presents current calculation methods for cost optimality calculations. This report was commissioned by the RGD and performed by dGmR.

RHDHV
16 May 2013 – *EPC aanscherpingsmethodiek Woningbouw en Utilitieitbouw* [81]: study on feasibility and cost effectiveness of new building regulation (lowered EPC) towards 2015.
12 Apr 2013 – *Memo Verbetervoorstel kostenoptimaliteit* [82]: proposals for deviating cost optimality methods described in the report ‘EPC aanscherpingsmethodiek’ from May 2013.

Appendix X Reproduction dGmR study

In this appendix a standard LCC calculation for a medium sized office building is performed to reproduce the results obtained in the dGmR study on the cost optimality of energy saving measures (March 11th 2013) [80]. The three best energy saving measure packages are being reproduced; results produced in this reproduction exercise lead into similar result as in the dGmR study.

Principles
The medium sized office building from the dGmR report was used in this LCC calculation. Properties of the reference office building are shown in Table 34. The reference building actually exists from a main building (3 stories) and a conference room. In this calculation only the main office building has been calculated.

Table 34: Properties of the refference office building (medium) used in the dGmR study. [153]

	Office building medium		
	Office building	Conference room	
Floor surface (A_{BVO})	5400	600	m^2
Percentage of A_{BVO}	90	10	%
User surface (A_g)	4320	480	m^2
Geometry			
Number of building layers	3	1	-
Depth	15	25	m
Width	120	24	m
Height	10.6	3.6	m
Volume	19440	2160	m^3
Construction			
Percentage of glass	30	30	%
Window (U-value) - Glass and frame	2.2	2.2	$W/(m^2K)$
Insulation (R_c-value) - Roof - Facade - Floor	4.0 4.0 4.0	4.0 4.0 4.0	m^2K/W m^2K/W m^2K/W
Installations			
Heating system	High Efficiency boiler HR 107 (≥ 55°C)	High Efficiency boiler HR 107 (≥ 55°C)	
Heating power	209		W
Cooling system	Compression cooling	Compression cooling	
Cooling power	244		W
Ventilation system	Mechanical (inlet/outlet)	Mechanical (inlet/outlet)	
Ventilation control	Heat recovery 65%	Heat recovery 65%	
Ventilation rate	53000	7700	m^3/h
Ventilation power	24	4	kW
Tap water system	Electric boiler (tap point within 3m)	Electric boiler (tap point within 3m)	
Lighting system	Daylight control or switch	Room controlled	
Lighting power	8	8	W/m^2
Q/Q	0.99		

First was determined which energy saving measures resulted into the best EPC score for the office building. From Table 35 can be seen that energy saving measure 12, 14 and 15 results in the highest ΔQ_{ratio}. This is the offset from the reference EPC score 0.99 shown in Table 34.

Table 35: Results of energy saving measure packages on the reference office building (medium). [153]

Rekenresultaten

gebouw	nr.	maatregel(pakket)	annuïteit (eur/m²/jaar)	CO_2 (kg/m²)	ΔQ_{ratio}
kantoor klein	9	wp retour, Uraam1,8	0,07	10,7	0,355
kantoor klein	10	vent werk toer, Uraam1,8	-0,1	1,8	0,042
kantoor middel	1	glasperc 50%	-1,1	n	-0,113
kantoor middel	2	dagveeg	0,0	1,0	0,024
kantoor middel	3	veegdagl alleen kantoor	0,0	0,8	0,019
kantoor middel	4	aanw det	-1,0	1,6	0,037
kantoor middel	5	wp aq	1,0	6,3	0,256
kantoor middel	6	wp aq ko	1,0	6,3	0,256
kantoor middel	7	daglicht bijeenk	0,0	0,1	0,003
kantoor middel	8	veeg bijeenk dagveeg kantoor	0,0	1,0	0,022
kantoor middel	9	wp buitenlucht	0,9	5,5	0,236
kantoor middel	10	wtw 70%	-0,48	0,7	0,021
kantoor middel	11	wp aq ko dagveeg kant bijeenk	0,93	7,4	0,280
kantoor middel	12	wp aq ko dagveeg kant bijeenk, aanw det	-0,10	8,8	0,313
kantoor middel	13	wp aq ko dagveeg kant bijeenk wtw70	0,40	7,9	0,292
kantoor middel	14	wp aq ko dagveeg kant bijeenk wtw70 aanw det	-0,63	9,4	0,324
kantoor middel	15	wp buit dagveeg kant bijeenk wtw70 aanw det	-0,68	8,5	0,305
kantoor middel	16	wp buit dagveeg kant bijeenk wtw70	0,35	7,1	0,273
kantoor groot	1	glasperc 50%	-1,0	n	-0,113
kantoor groot	2	wp aq	1,3	6,8	0,284

The three best energy saving measure packages are used in this LCC calculation:

12. ATES, advanced lighting system (presence/daylight sensors)
14. ATES, advanced lighting system (presence/daylight sensors), heat recovery 70%
15. Air-to-air heat pump, advanced lighting system (presence/daylight sensors), heat recovery 70%

The measures mentioned above replace the standard measures described in Table 34.

Method

The LCC calculation has been executed in the same manner as described in chapter 5.2. The following four cases have been calculated:

- Km_{ref} → Reference building (Table 34)
- Km_1 → Reference building with energy saving package 12
- Km_2 → Reference building with energy saving package 14
- Km_3 → Reference building with energy saving package 15

The financial and macro-economic analyses were performed with the values from the dGmR report. Table 36 and Table 37 show parameters that differ and that are identical for this LCC calculation. For the reproduction of the dGmR results exactly the same parameters have been used, for the RHDHV cost optimality calculations more recent values are used.
The only major difference in the calculation is the investment cost; these values have been updated to present (2013) values.

Table 36: LCC parameters which differ from RHDHVcost optimality calculations. [81][82][153]

	dGmR (report 03-2013)	RHDHV (dGmR reproduction)	RHDHV (cost optimality)
Inflation rate	0 %	0 %	2,8 %
Discount rate - Financial analysis - Macro-economic analysis	 8.0 % 3.0 %	 8.0 % 3.0 %	 6.4 % 2.0 %
Energy price increase (for utility buildings) - Electricity - Gas	 1.8 % 1.5 %	 1.8 % 1.5 %	 2.8 % 2.8 %
Financing interest	0 %	0 %	2.3 %
Sensitivity analysis - Financial analysis - Macro-economic analysis	 6.5% and 9.0% 1.0% and 3.0%	 6.5% and 9.0% 1.0% and 3.0%	 4.9% and 7.9% 1.0% and 3.0%

Table 37: LCC parameters identical for all calculations. [81][82][153]

For all studies
VAT and taxes • Financial analysis → including VAT and taxes • Macro-economic analysis → excluding VAT and taxes
CO_2 emission costs • Financial analysis → excluding CO_2 emission costs • Macro-economic analysis → including CO_2 emission costs
Energy prices scenarios • + 20% • – 20%

Energy price course

The course of energy prices is of importance for the financial feasibility of energy saving measures for nZEBs. This section shows the history and future trends of prices for gas and electricity in the Netherlands.

The prices of gas and electricity during the past decade for small users (residential and utility buildings) are shown in Figure 62 and Figure 63, respectively. [154] These values show average prices (no day or night tariffs included) that energy companies charge for their services (including network costs, transport costs, delivery costs). The prices are including VAT but excluding energy taxes. Both graphs show great increases in energy prices; the price of electricity has almost doubled over the past decade.

To have an idea on Dutch energy consumption: the average energy consumption for a household is 1500 m^3 natural gas and 3500 kWh electricity. [155]

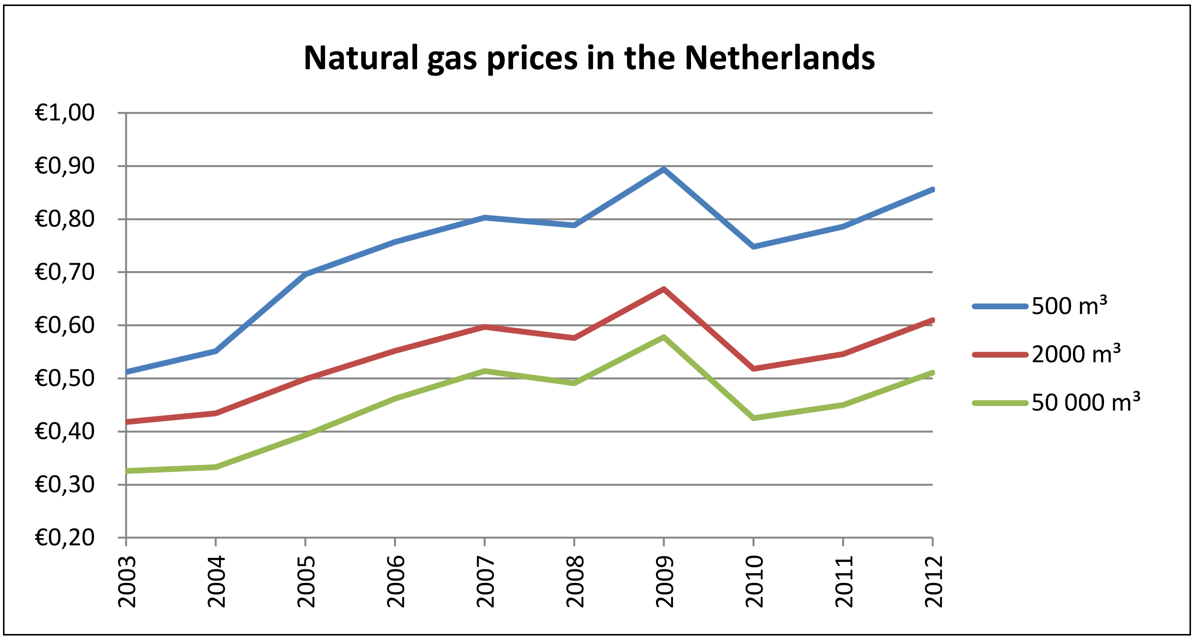


Figure 62: Natural gas prices in the Netherlands in the period 2003-2012. [154]

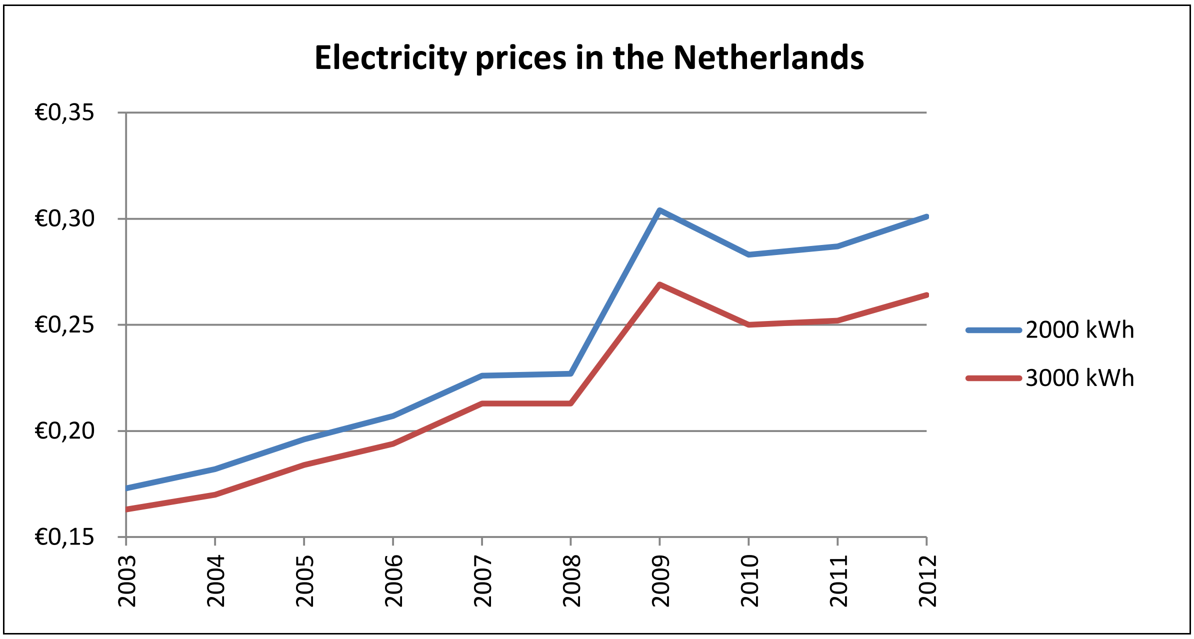


Figure 63: Electricity prices in the Netherlands in the period 2003-2012. [154]

The future energy price scenarios are important for the financial feasibility of energy saving measures. Table 36 shows the average energy price increase for both the dGmR study and this RHDHV study. The difference in energy price increase is quite significant: 1.5% and 1.8% for the dGmR study, and 2.8% for this RHDHV study. A higher energy price is beneficial for energy saving measures, since the PBP will be shorter. The energy price scenarios used for both studies are discussed in the following paragraphs.

The energy price scenarios in the dGmR study are based on two sources:

- ECN (Energieonderzoek Centrum Nederland) research on energy prices and discount rates for building energy performance relating to the EPBD. [156]
- Energy prices tool of Agency NL, results shown in dGmR report, bijlage 1. [80]

The energy price scenario used by dGmR includes values from 2012 until 2041. Till the year 2040 energy prices were available, but the last year has been linearly extrapolated. The average gas price increase is 2.0% and 1.8% for residential and utility buildings, respectively. The average electricity price increase is 1.0% and 1.5% for residential and utility buildings, respectively.
The energy price scenarios (gas and electricity) including energy taxes for residential and utility buildings are shown in Figure 64, Figure 65, Figure 66, and Figure 67.

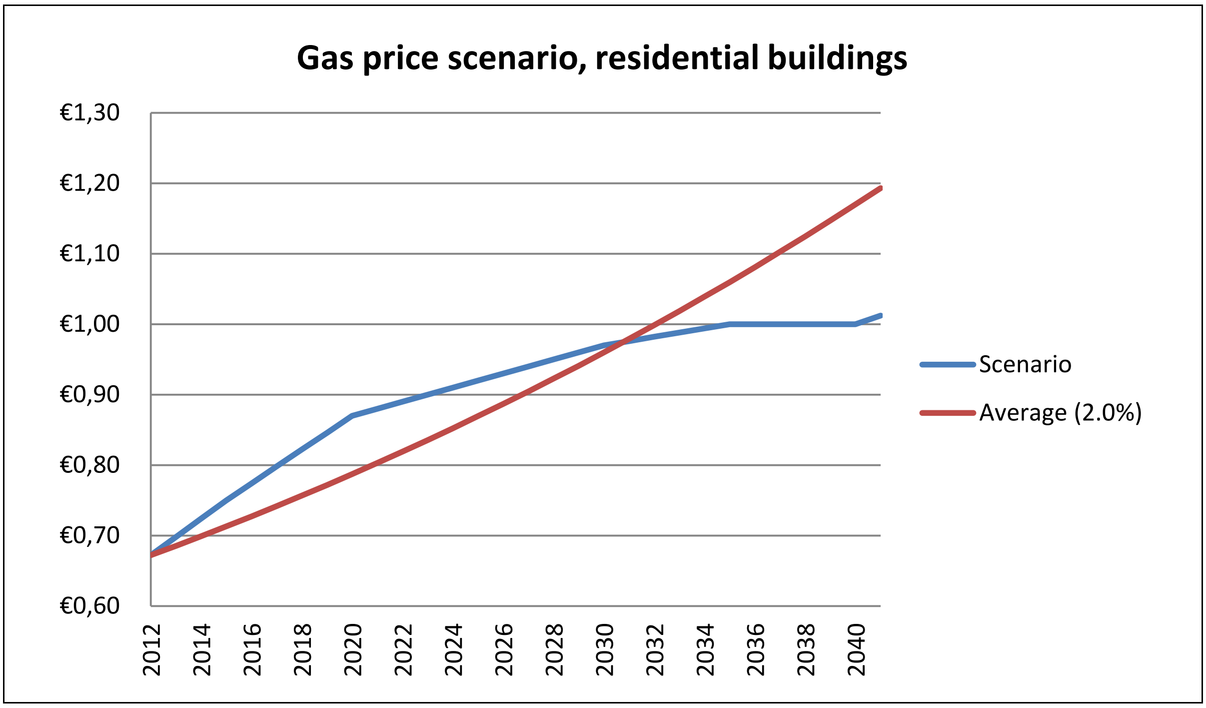


Figure 64: Gas price scenario for residential buildings for the period 2012-2041. [80]

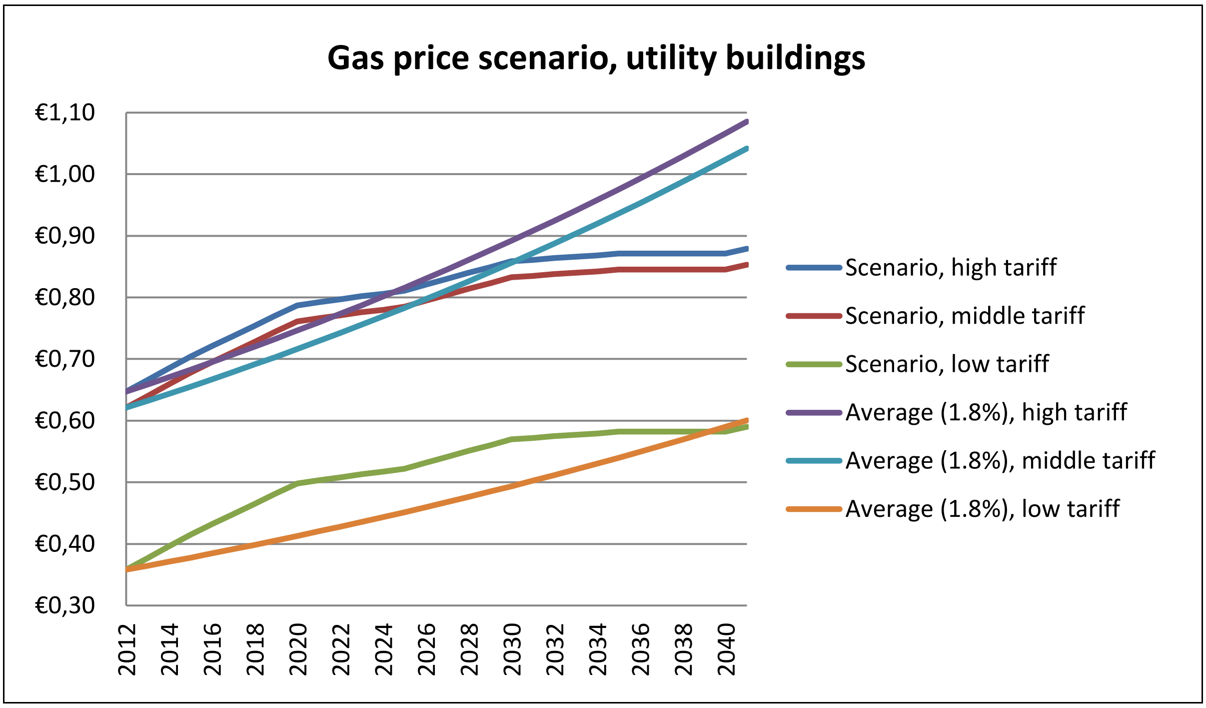


Figure 65: Gas price scenario for utility buildings for the period 2012-2041. [80]

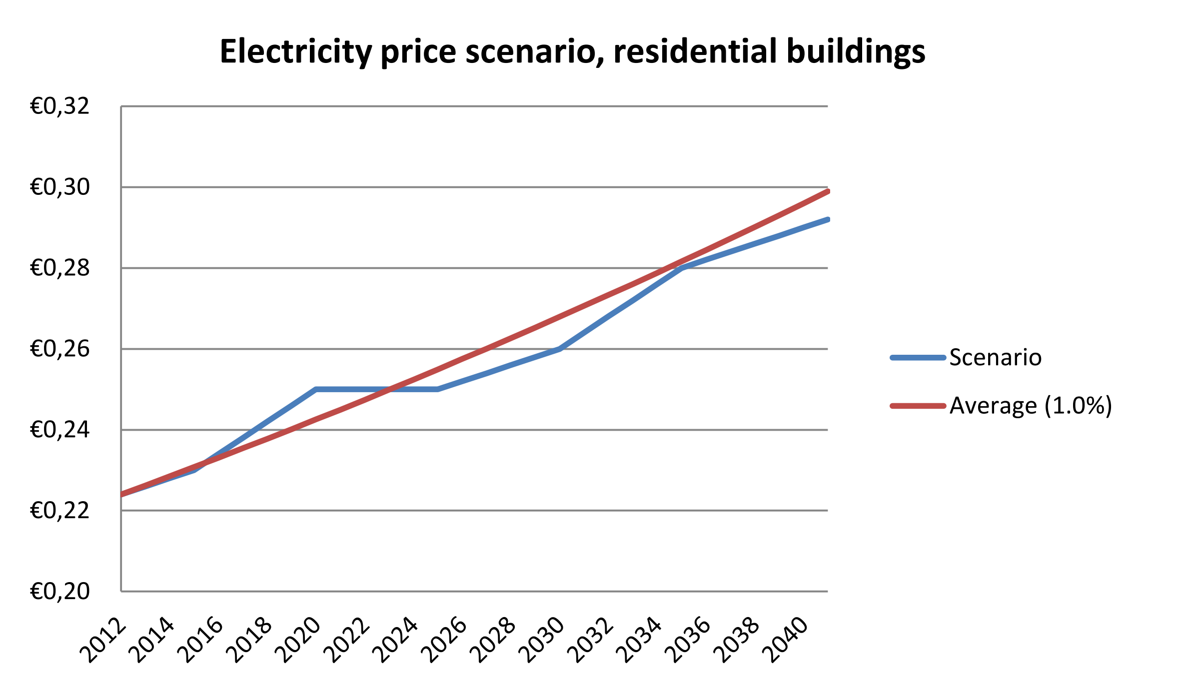


Figure 66: Electricity price scenario for residential buildings for the period 2012-2041. [80]

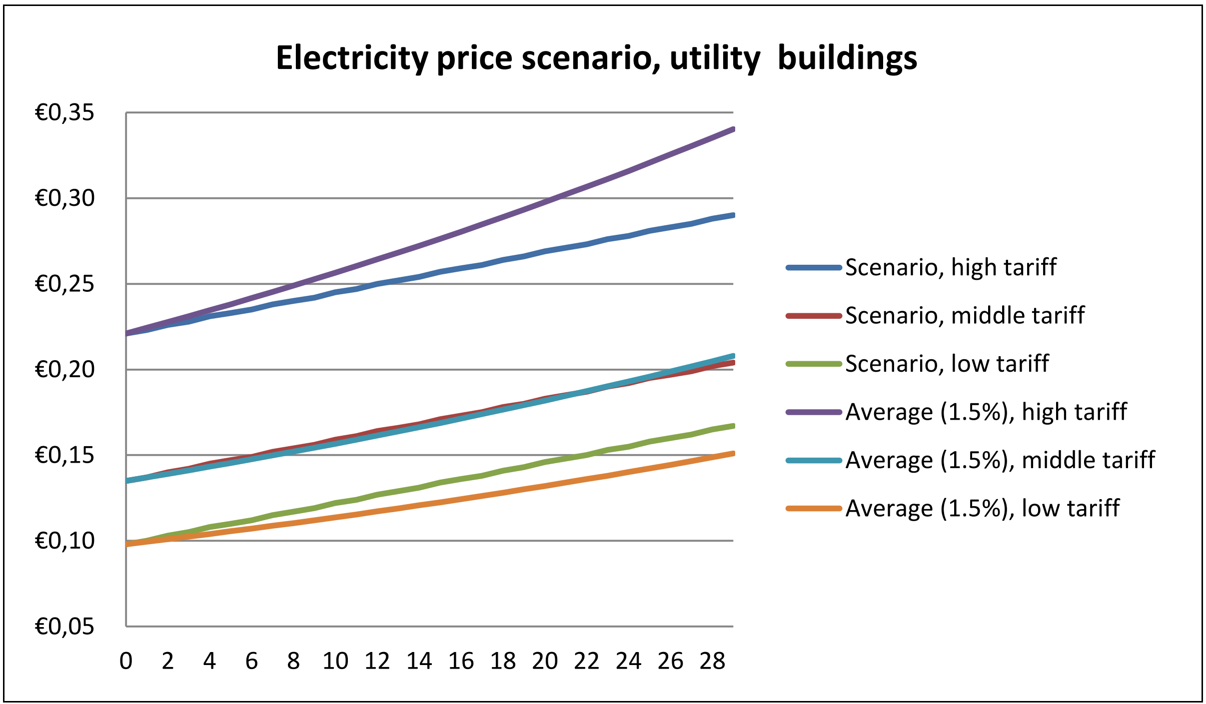


Figure 67: Electricity price scenario for utility buildings for the period 2012-2041. [80]

From the graphs above can be seen that the average energy price increase does not always match with the scenarios, as seen in Figure 64, Figure 65 (gas price, high and middle tariffs), and Figure 67 (electricity price, high tariff). This deviation can lead to unrepresentative LCC calculations, benefitting the energy saving measures in the dGmR study.

The energy price scenarios in this RHDHV study used the following source:

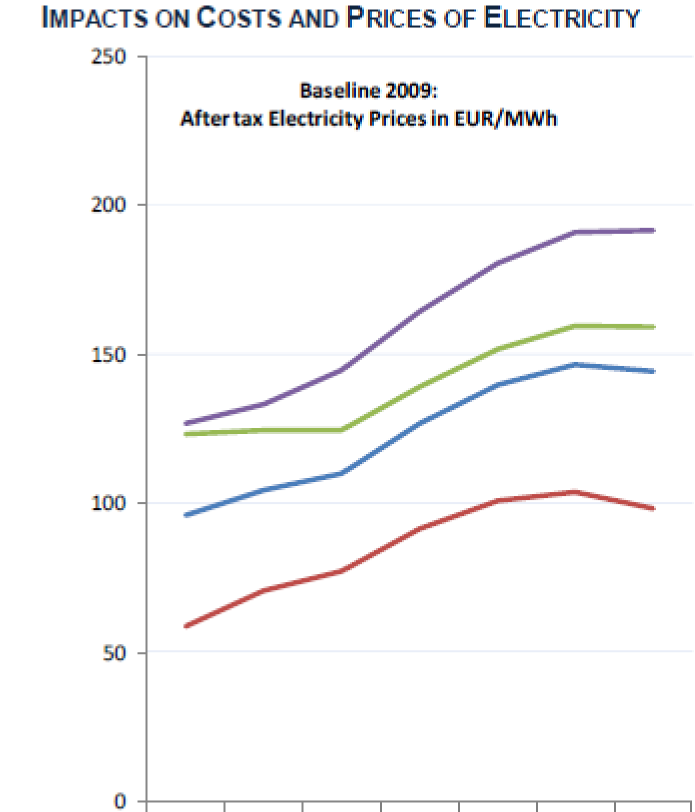
- Office Journal of the EU on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels. [150]
- European Commission, Directorate-General for energy – EU Energy Trends up to 2030 (update 2009). [157]

The latest update from [157] implies a 2.8% annual increase in gas prices, a 2.8% annual increase in oil prices and a 2% annual increase in coal prices. These trends may be extrapolated beyond 2030 until more long-term projections become available.

Figure 68 and Figure 69 show the cost price of electricity and world fossil fuel prices, respectively

The electricity price in Figure 68 does not show a continuous inclination like Figure 66 and Figure 67, but the prices levels of.

The gas price scenario in of Figure 69 does show a similar trend compared to Figure 64 and Figure 65: a quite steep inclination in gas prices can be found till the year 2030.



	2000	2005	2010	2015	2020	2025	2030
Average	96	104	110	127	140	146	144
Industry	59	71	77	92	101	104	98
Services	123	124	124	139	152	159	159
Households	127	133	144	164	180	191	192

Figure 68: European electricity price scenario

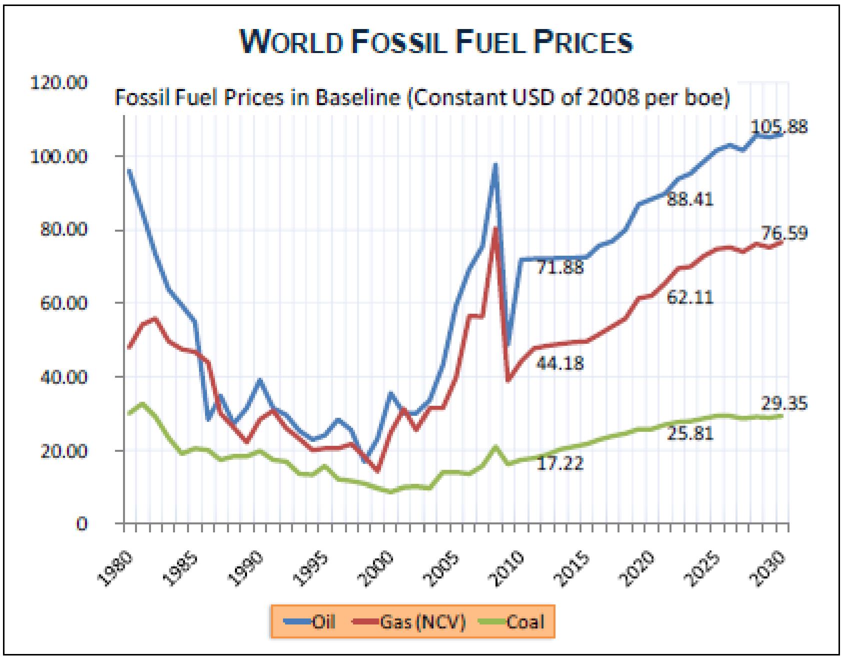


Figure 69: World fossil fuel prices scenario.

The energy prices scenarios for the dGmR study and this RHDHV study shows some deviation that can influence the results of the LCC calculation. All scenarios are marked by uncertainties which influence the energy price.
The energy price, and especially the gas price, may be heavily influenced by the discovery of shale gas fields. In the United States (US) gas prices have dropped significantly since the large scale extraction of scale gas, as can be seen in Figure 70. Gas price in the Netherlands (€28 per MWh) is almost three times higher compared to the US (€10 per MWh). This however does not directly influence gas prices in Europe, due to strict export restrictions in the US. Low US gas prices do influence world coal price, since the US now consumes less of it; this major structural change has effect on the European electricity price. [158]
The development of energy prices in Europe (and the Netherlands) may depend to a great extent on the direction of European policy on extraction of scale gas.

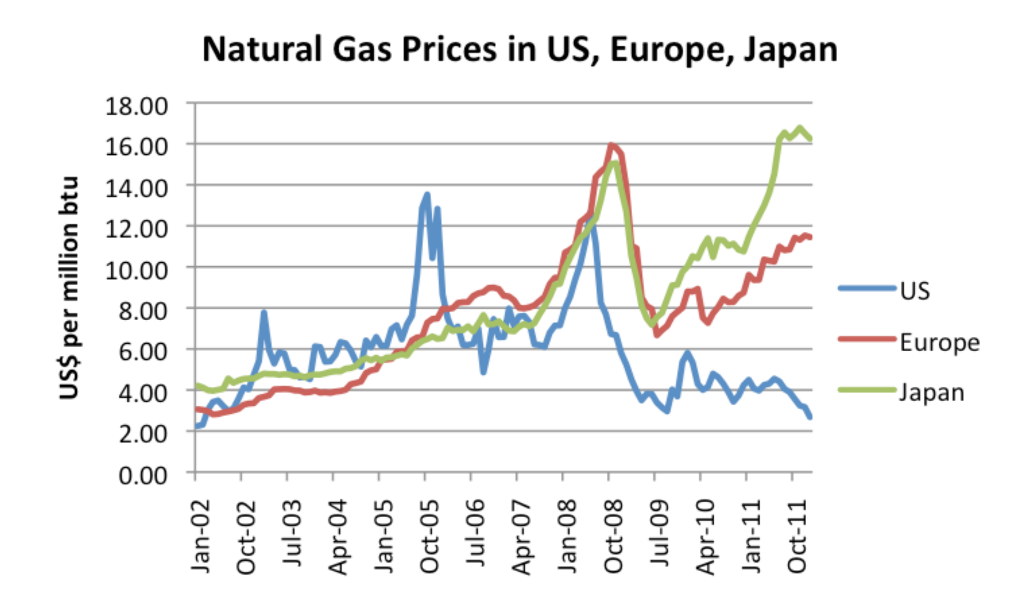


Figure 70: Natural gas prices in United States, Europe and Japan. [159]

Comparison of results
For the medium sized office building, used in the dGmR study, a financial and micro economic analysis has been performed to compare the results. The results are shown in the following this section.

The resulting graphs show the Net Constant Costs (NCC) per square meter versus the Q/Q. This is ratio between characteristic energy consumption of the building and the allowable energy performance set by the Dutch government. For office buildings the EPC = 1.1, which means that a Q/Q = 1.00 is equal to EPC = 1.1. From Table 34 can be seen that the reference building satisfies the EPC of 1.1.

Figure 71 till Figure 74 show the results of the financial and macro-economic analysis for both the dGmR study and this reproduction calculation. The black arrows in Figure 71 and Figure 73 appoint the three cases (energy saving packages 12, 14, and 15) that were being reproduced.
From all figures (Figure 71 and Figure 72, Figure 73 and Figure 74) great similarities can be seen, which proves the method of this LCC calculation provide accurate results.

Financial analysis – dGmR study

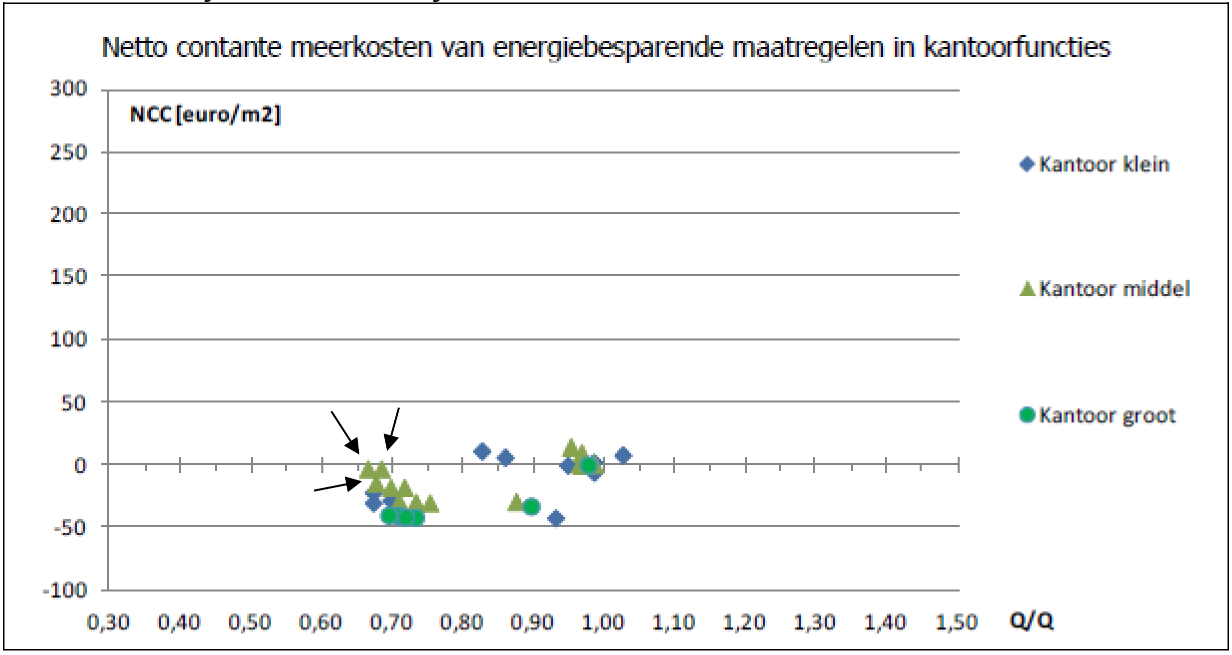


Figure 71: Financial analysis dGmR study: Net Constant additional costs of energy saving measures for office buildings. [80]

Financial analysis – RHDHV reproduction

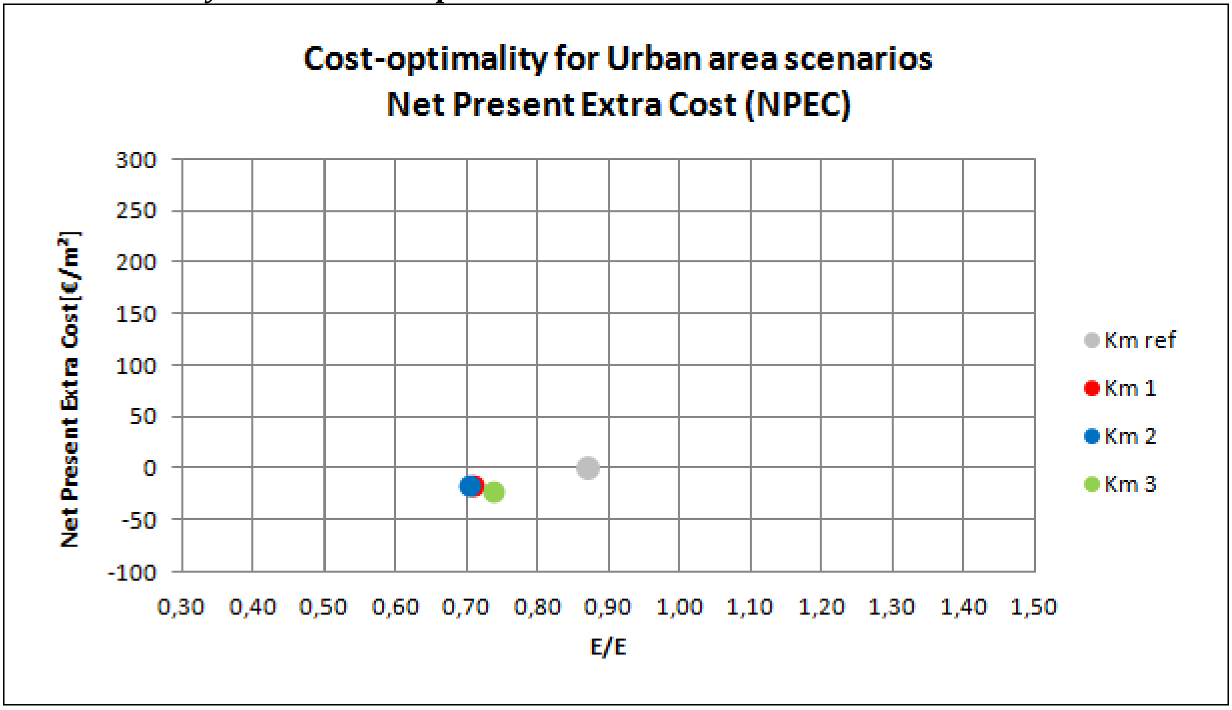


Figure 72: Financial analysis reproduction: Net Constant additional costs of energy saving measures for middle sized office buildings.

Macro-economic analysis – dGmR study

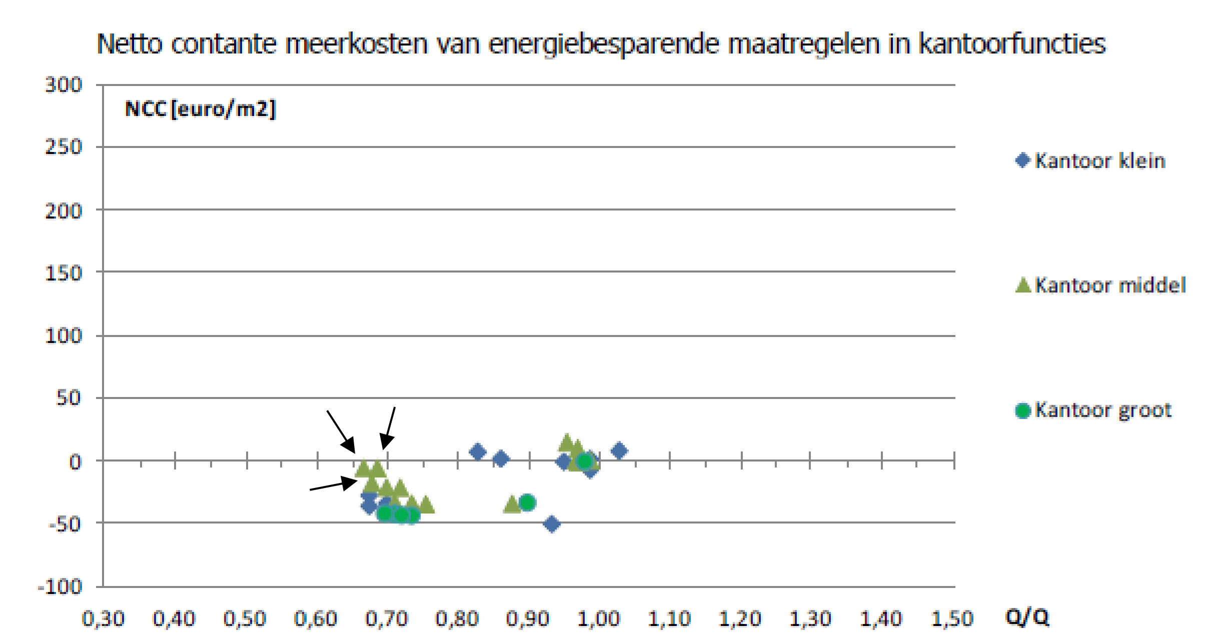


Figure 73: Macro-economic analysis dGmR study: Net Constant additional costs of energy saving measures for office buildings. [80]

Macro-economic analysis – RHDHV reproduction

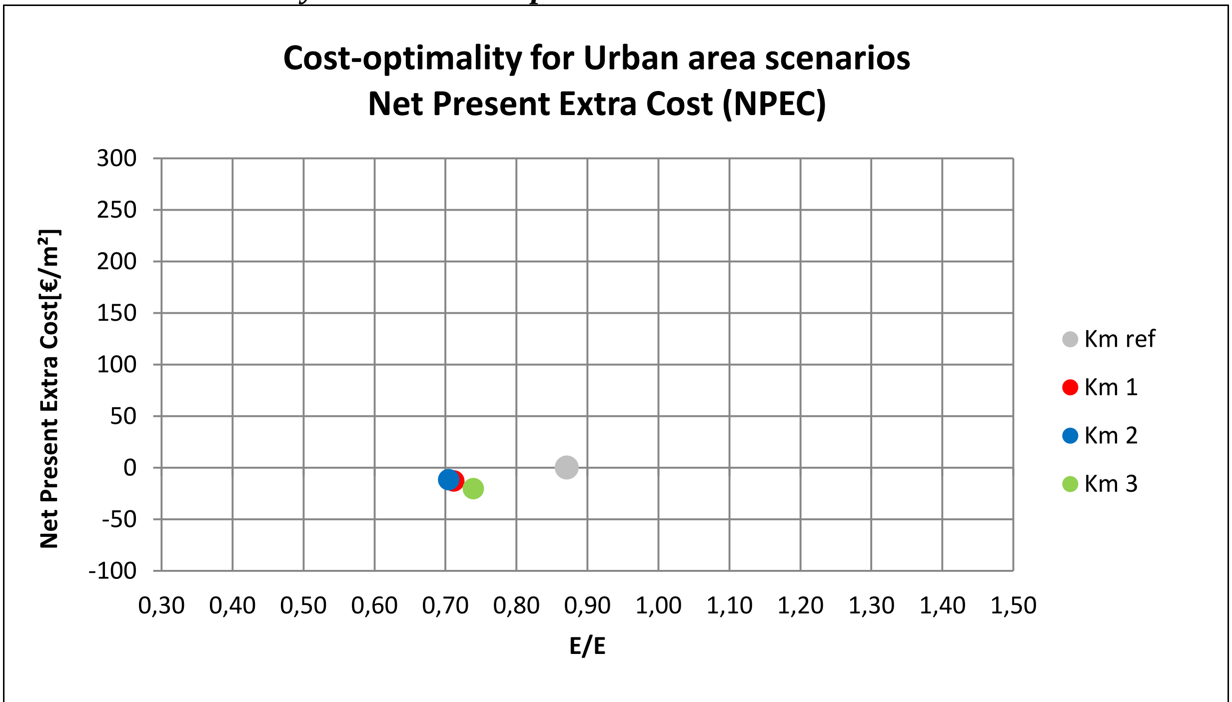


Figure 74: Macro-economic analysis reproduction: Net Constant additional costs of energy saving measures for middle sized office buildings.

Appendix XI LCC' calculation

This sheet shows the input values used in the LCC' calculation.

Variated CAPEX	Description	Dispersion min	max	Value	Unit	Uref	U1	U2	U3
CAPEX [€/m²]		min	max			1.702	1.811	1.814	1.825
Architect				8%	%	€ 69,72	€ 72,21	€ 72,21	€ 72,21
Advisor installations		4%	5%	4,5%	%	€ 2,22	€ 5,42	€ 5,56	€ 6,02
Construction manager		1%	1%	1%	%	€ 9,21	€ 10,23	€ 10,26	€ 10,36
Land costs		350	900	€ 700,00	[€/m²]	€ 700,00	€ 700,00	€ 700,00	€ 700,00
Building costs									
Building costs	Building construction (building frame + facade + roof + finishing + …)					€ 843,32	€ 843,32	€ 843,32	€ 843,32
Additional costs	Additional cost for improved insulation and glazing					€ 28,13	€ 59,35	€ 59,35	€ 59,35
Elektrotechnical installations									
Lighting	Energy efficient lighting with daytime sensors presence sensors					€ 3,03	€ 3,03	€ 3,03	€ 3,03
PV panels (roof and/or facade)	PV panel + converter + brackets					€ 11,48	€ 74,02	€ 74,02	€ 74,02
Mechanical installations	(heating, cooling, hot tap water, ventilation, humidifier)								
Heating & cooling									
Heat pump						€ 8,93	€ 10,10	€ 10,10	€ 10,10
Well	Ground soures, Aquifer, Road collector					€ 14,84	€ 16,79	€ 20,06	€ 30,12
Hot tap water	Electric boiler (4x)					€ 0,33	€ 0,33	€ 0,33	€ 0,33
Ventilation	Balanced ventilation					€ 5,54	€ 10,80	€ 10,80	€ 10,80
Humidifier	Humidifier unit (6x)					€ 5,27	€ 5,27	€ 5,27	€ 5,27

Variated Energy		Excluding	Including	Value	Unit	Uref	U1	U2	U3
*Energy [€/(m²*yr)]*						4,34	0,43	0,13	0,28
Electricity		Excluding	Including		[€/kWh]				
Consumption > 50,000 kWh		€ 0,055	€ 0,141	€ 0,14	[€/kWh]	€ 4,34			
Consumption < 50,000 kWh		€ 0,059	€ 0,119	€ 0,12	[€/kWh]		€ 0,43		
Consumption < 10,000 kWh		€ 0,061	€ 0,220	€ 0,22	[€/kWh]			€ 0,13	€ 0,28
Gas				0,64	[€/m³]				
Water				1,76	[€/m³]				
Biomass									

Variated OPEX	Description	Min	Max	Value	Unit	Uref	U1	U2	U3
*OPEX [€/(m²*yr)]*		Min	Max			42	4	4	5
Maintenance									
Building - Prevention/Correction		1,90%	1,90%	1,90%	%	€ 16,56	€ 17,15	€ 17,15	€ 17,15
E - Prevention/Correction		2,20%	2,20%	2,20%	%	€ 0,32	€ 1,70	€ 1,70	€ 1,70
W - Prevention/Correction		3,20%	3,20%	3,20%	%	€ 1,12	€ 1,39	€ 1,49	€ 1,81
Cleaning		€ 15,80	€ 17,00	€ 17,00		€ 17,00	€ 17,00	€ 17,00	€ 17,00
Taxes		0,34%	0,34%	0,34%	%	€ 5,79	€ 6,16	€ 6,17	€ 6,20
Insurrance		0,05%	0,06%	0,06%	%	€ 1,02	€ 1,09	€ 1,09	€ 1,09
Electricity production (PV)									
Inported electricity	Buying price of electricity								
Exported energy	Selling prices of electricity	see table ->							
No gass connection	(same for all concepts)								
ADDITIONAL GAINS									
Sick leave reduction		2,04	days	€ -13,60	€/(m²a)		€ -13,60	€ -13,60	€ -13,60
Prodcutivity				€ -26,50	€/(m²a)		€ -26,50	€ -26,50	€ -26,50
PR-value	Not able to quantify costs								
Higher renting price	Not able to quantify costs								
Road Collector	Not able to quantify costs								

Variated End Value	Uref	U1	U2	U3
End Value [€/m²]	1.193	1.209	1.209	1.209
Residual value				
Building	€ 435,72	€ 451,34	€ 451,34	€ 451,34
Land	€ 700,00	€ 700,00	€ 700,00	€ 700,00
Installation (well)				
Lighting system	€ 2,43	€ 2,43	€ 2,43	€ 2,43
Dismounting	€ 40,00	€ 40,00	€ 40,00	€ 40,00
Disposal costs	€ 15,00	€ 15,00	€ 15,00	€ 15,00
ADDITIONAL GAINS				
Higher end value (green image)				

Table 38: Lifetime of construction measures and installations. [81]

	Lifetime [year]
Construction	
Insulation (wall, roof, floor)	50
Glass	50
Installation	
Heat pump (GSHP and ATES)	15
Aquifer well	15
Ventilation system (+ heat recovery)	15
PV panel	15
Energy efficient lighting	25

The lifetime of construction materials and building installations are based on the RHDHV report [81]. Lifetimes used in the LCC' calculation are listed in Table 38.

Appendix XII Cost optimality results

The results for the financial, macro-economic, and the sensitivity analysis are shown in a graphical representation with LCC [€/m²] versus primary energy demand [kWh/(m^{2}a)].

Financial analysis

Figure 75 and Figure 76 show the results of the financial analysis without and with additional gains, respectively.

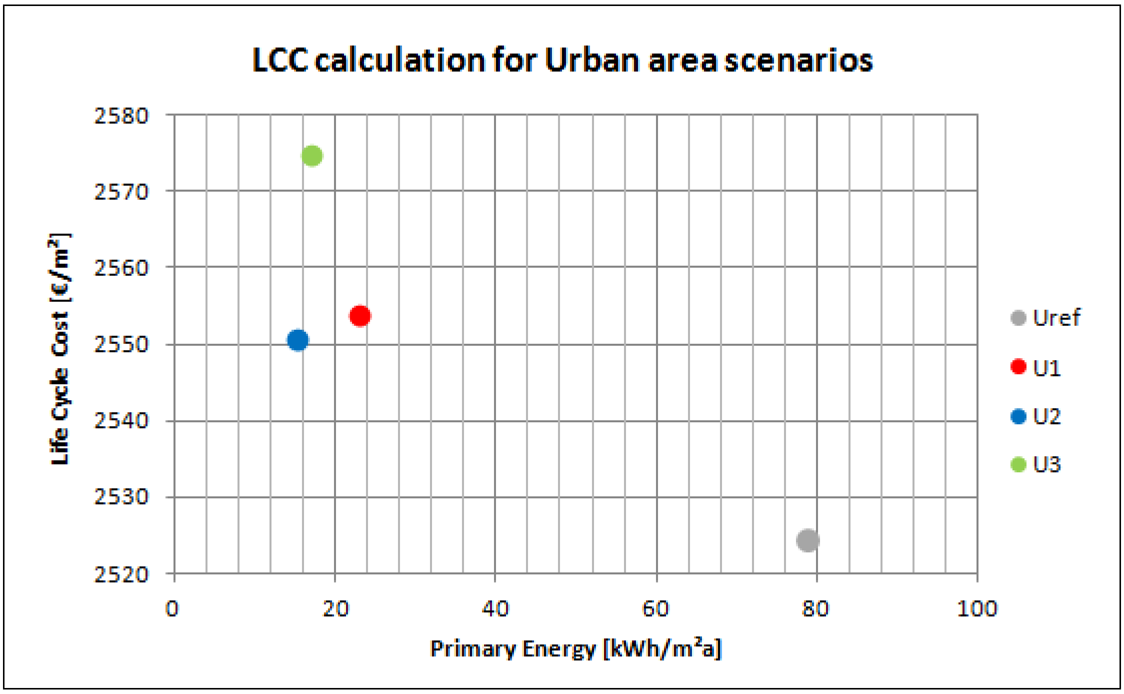


Figure 75: Financial analysis <u>without additional gains</u> for Urban area scenarios: office building.

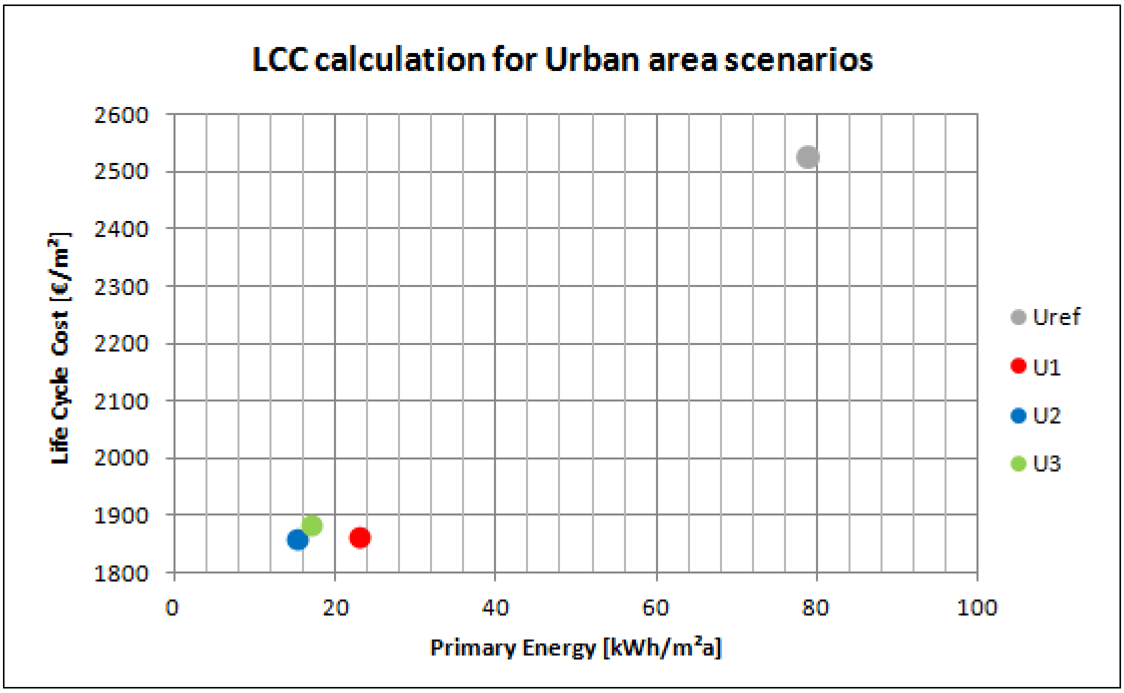


Figure 76: Financial analysis <u>with additional gains</u> for Urban area scenarios: office building.

Macro-economic analysis

Figure 77 and Figure 78 show the results of the macro-economic analysis without and with additional gains, respectively.

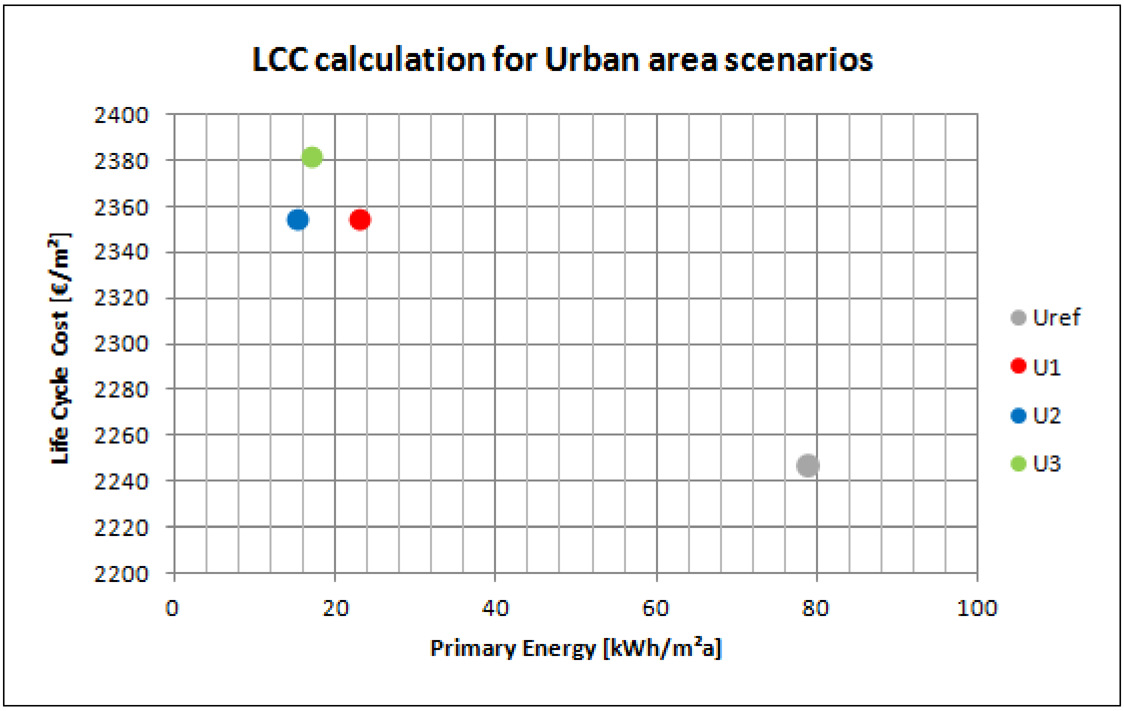


Figure 77: Macro-economic analysis <u>without additional gains</u> for Urban area scenarios: office building.

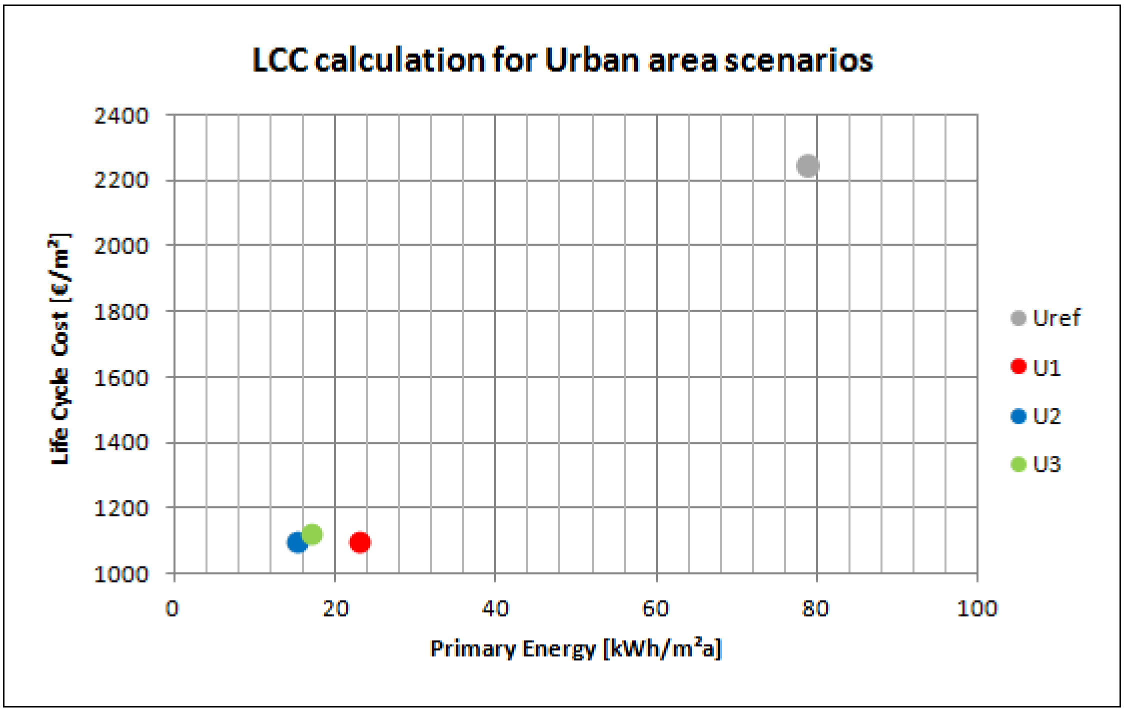


Figure 78: Macro-economic analysis <u>with additional gains</u> for Urban area scenarios: office building.

Sensitivity analysis

The sensitivity analysis has been performed for the cost optimality calculation only with additional gains. Both the sensitivity of the financial and the micro economic analysis have been tested for minimum and maximum discount rates and energy price scenarios.

Financial analysis

Figure 79 and Figure 80 show the sensitivity of the financial analysis (with additional gains) with a discount rate of 4.9% and 7.9%, respectively.

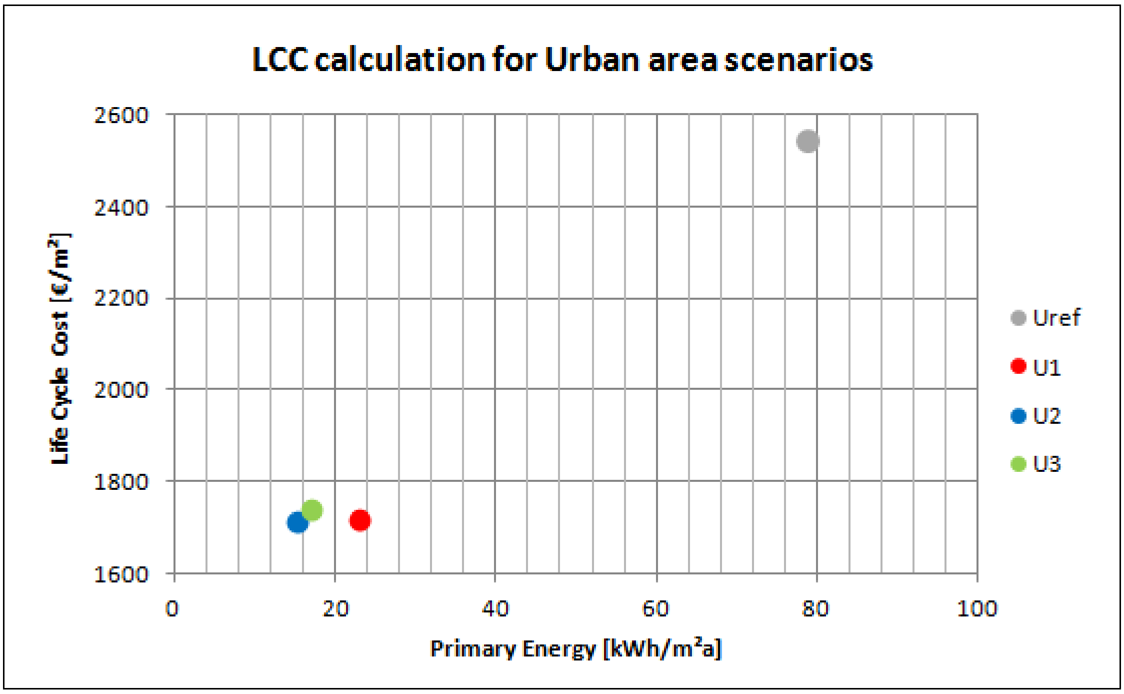


Figure 79: Sensitivity (discount rate of 4.9%) of financial analysis with additional gains.

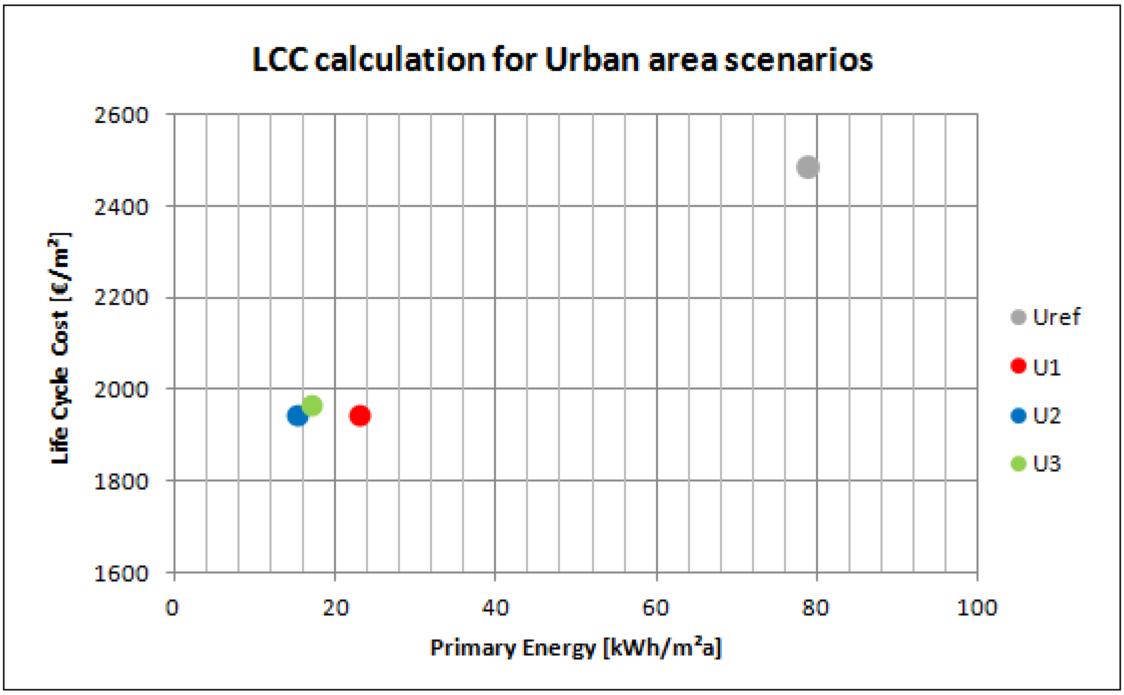


Figure 80: Sensitivity (discount rate of 7.9%) of financial analysis with additional gains.

Micro economic analysis

Figure 81 and Figure 82 show the sensitivity of the micro economic analysis (with additional gains) with a discount rate of 1.0% and 3.0%, respectively.

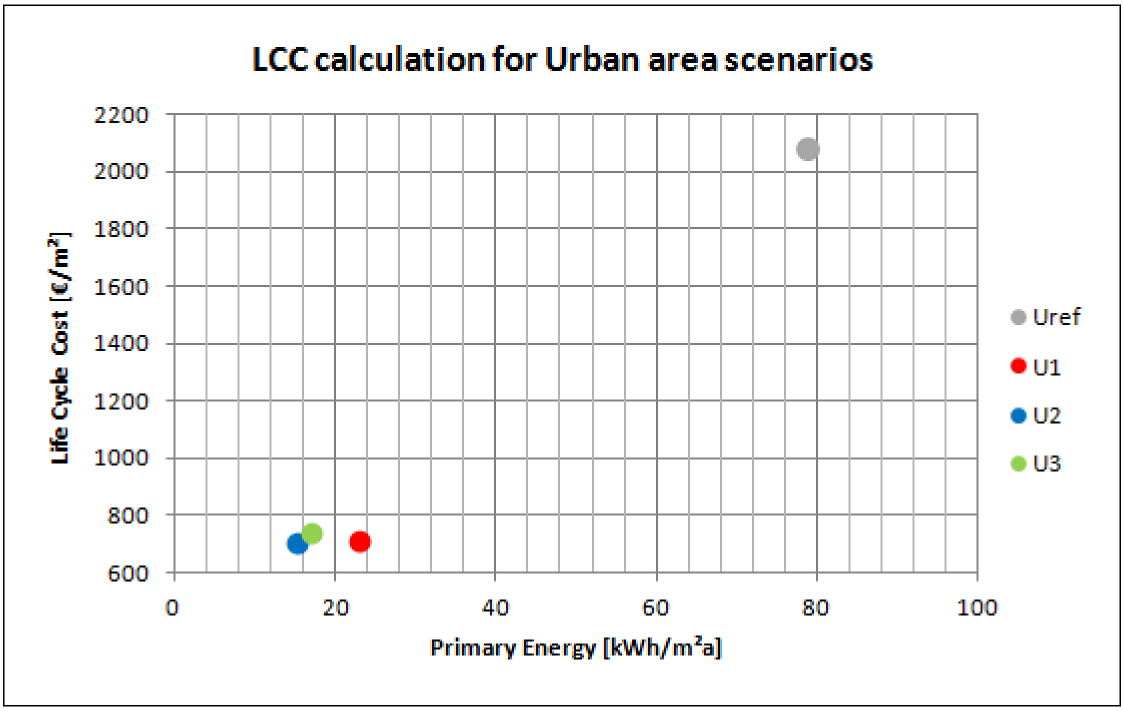


Figure 81: Sensitivity (discount rate of 1.0%) of macro-economic analysis with additional gains.

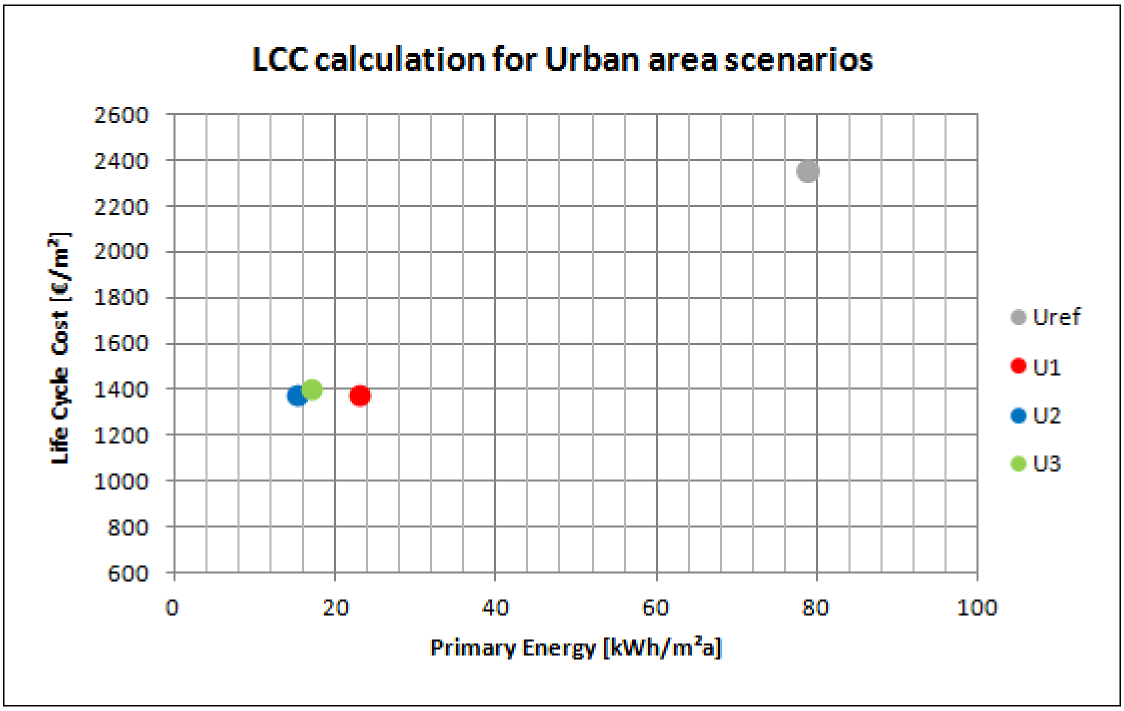


Figure 82: Sensitivity (discount rate of 3.0%) of macro-economic analysis with additional gains.

Energy price scenario for financial analysis

The energy price scenario has been performed for the financial analysis and has been calculated using the standard discount rate of 6.4%

Figure 83 and Figure 84 show the sensitivity of the financial analysis with additional gains with an energy price decrease and increase of 20%, respectively.

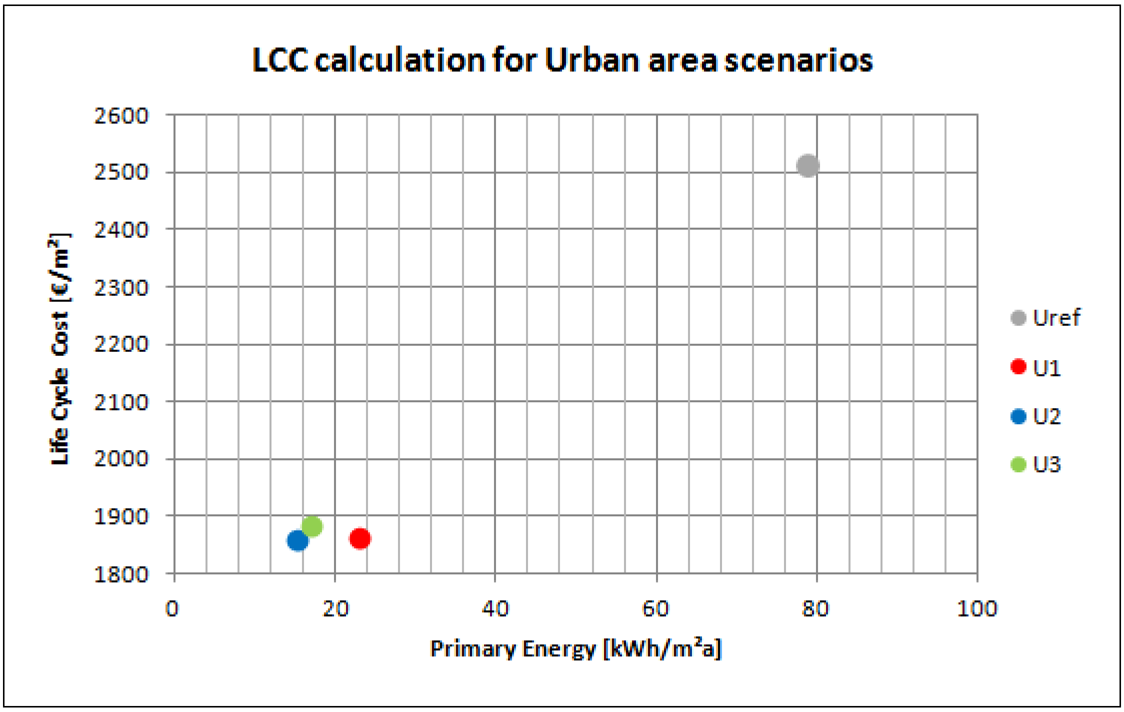


Figure 83: Sensitivity (energy price scenario of -20%) of financial analysis with additional gains.

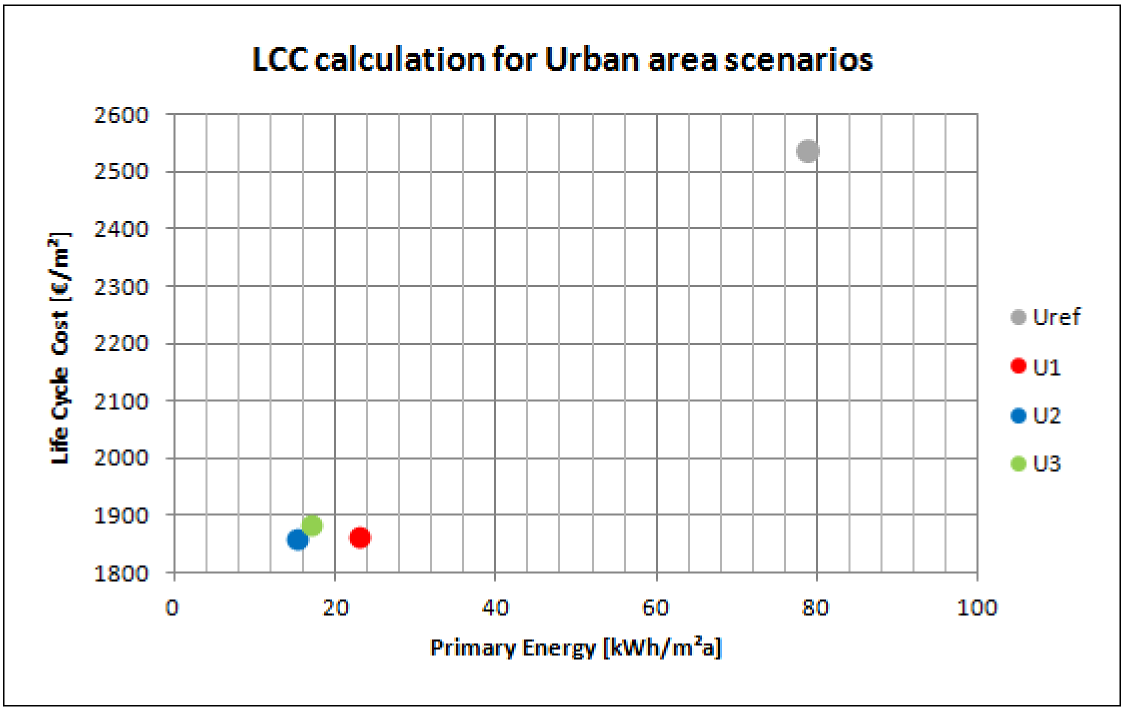


Figure 84: Sensitivity (energy price scenario of +20%) of financial analysis with additional gains.

Energy price scenario for macro-economic analysis
The energy price scenario has been performed for the macro-economic analysis and has been calculated using the standard discount rate of 2.0%

Figure 83 and Figure 84 show the sensitivity of the macro-economic analysis with additional gains with an energy price decrease and increase of 20%, respectively.

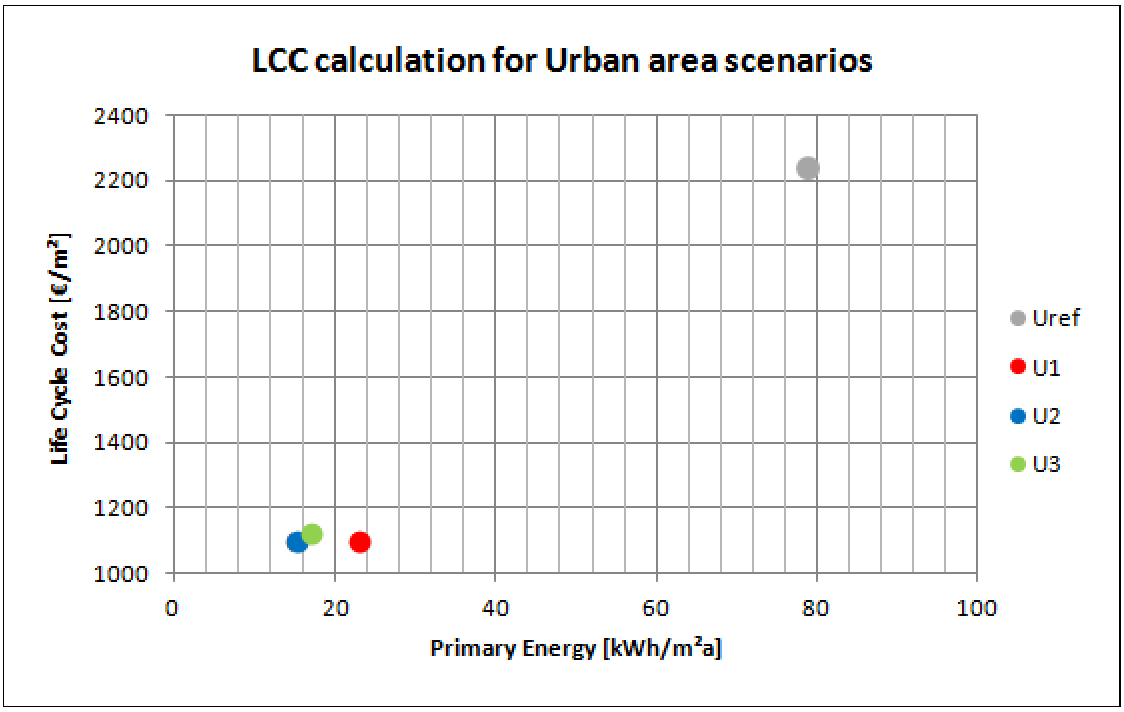


Figure 85: Sensitivity (energy price scenario of -20%) of macro-economic analysis with additional gains.

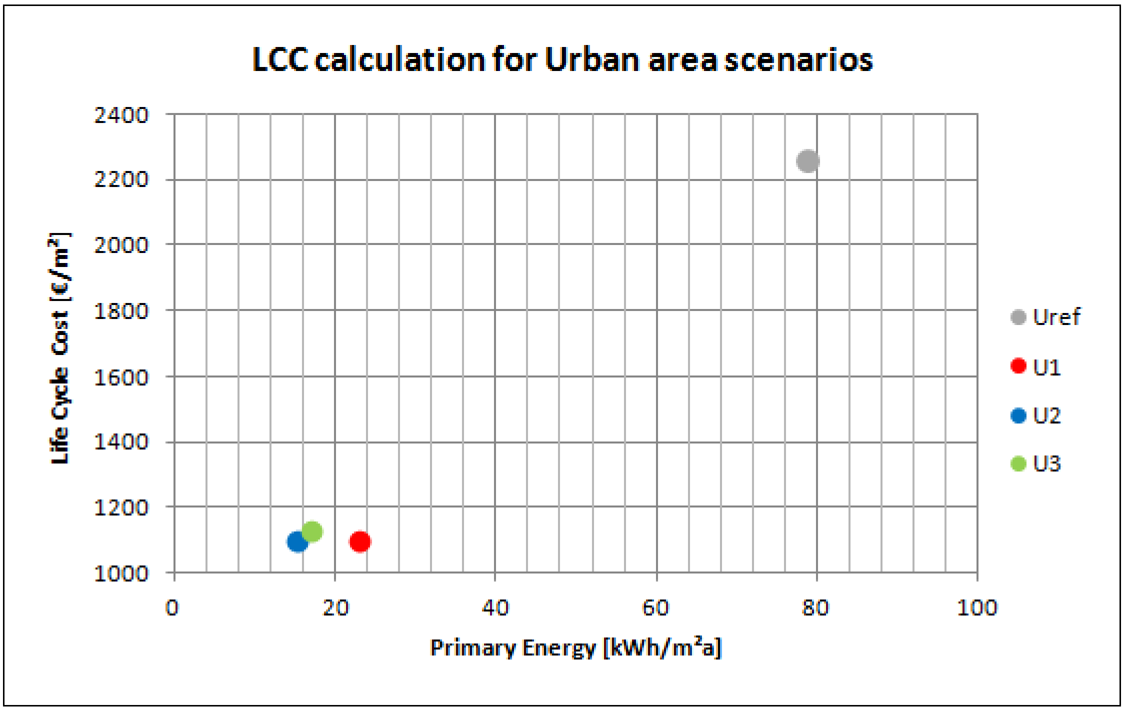


Figure 86: Sensitivity (energy price scenario of +20%) of macro-economic analysis with additional gains.