The ‘new’ zero energy office building

The impact of Dutch regulatory changes on the development of energy efficient office buildings.

Master thesis – Lukas van Veen – TU Delft – July 2020

BENG! The 'new' zero energy office building
The impact of Dutch regulatory changes on the development of office buildings

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Preface

This thesis is the result of the gradation research of the master track Management in the Built Environment (MBE) of the faculty of Architecture of the Technical University of Delft. MBE is divided into several studios. This thesis is written for the Real Estate Management (REM) studio.

My interest in the energy efficiency of the built environment was sparked during my bachelor's in architecture. The need for a more energy-efficient built environment is crucial in fighting global warming and climate change, and during my bachelor's, I learned that the techniques and technology for doing so are already at hand. In practice, however, zero energy buildings are rather the exception than the norm. This phenomenon fascinated me and drove my interest in this research topic. During this research, it quickly became apparent that in practice developing zero energy and energy-efficient (office) buildings is a complex process and needs the cooperation of many different stakeholders.

The research topic of this master thesis comes from a large interest in the energy efficiency in the built environment with an emphasis on the commercialization of this. I was always convinced of the commercial potential of energy efficient (office) buildings and my belief was something that there was no governmental steering needed for the energy transition of the built environment. During this research, I have changed my perspective. Although I am still convinced of the commercial potential of energy efficient (office) buildings, I now see that governmental steering and policies are key for the energy transition and developing a more sustainable built environment.

I would like to thank Hilde Remøy and Andy van den Dobbelsteen. They were my main mentors from the Technical University of Delft and guided me through the process of writing my thesis. Their knowledge and feedback were extremely valuable for bringing this research to the next level. Furthermore, I would like to thank Constantijn Berning and all my other colleagues at EDGE Technologies. The contacts, research data, and a pleasant work environment were crucial for the successful completion of this graduation research.

Lukas van Veen
Amsterdam, June 2020

Management summary

Introduction
In 2015 the United Nations formed the Paris Climate Agreement. The Paris Agreement aims to keep the average temperature rise on earth below 2 °C by reducing the total amount of CO_2 emissions of the 180 participating countries (United Nations, 2015). The built environment is a large contributor to the emission of greenhouse gasses and is responsible for approximately 40% of the total energy consumption in the European Union (EPRS, 2016). The European Union (EU) has introduced the Energy Performance of Buildings Directive (EPBD) as the legislative instruments to promote the improvement of the energy performance of buildings within the EU. The Netherlands, as a member state of the European Union, is obliged to establish regulations and policies to promote cost-effective renovation and energy efficiency improvement of their building stock (European Union, 2018). Because current policies do not fit the framework of the EPBD, the new energy efficiency regulation BENG and determination method NTA8800 are introduced in the Netherlands, which become effective January 2021.

This new regulation and determination method change the way how office buildings are currently developed. This research studies how zero-energy office buildings can be developed within the framework of these new policies. Therefore, the main research question of this thesis is: How can zero-energy office buildings be developed considering new energy regulations? The object of study is analysed from three perspectives: policies, the technical feasibility of zero-energy office buildings within the framework of new policies, and the financial feasibility of zero-energy office buildings within the framework of new policies.

Method
To answer the main research question, the research is divided in three successive parts: a literature study, an empirical research, and a research by design. The first part of the research will form the scientific framework. The part is an empirical research studying three cases of zero-energy office buildings within the framework of current energy efficiency policies. The first two research parts illustrate where bottlenecks are for zero-energy office buildings according to current and new policies. The third and final research part presents a technical design for developing zero-energy office buildings within the framework of the new policies. This Technical Design is validated by an expert panel and tested through redesigns for the studied cases. Lastly, the boundaries for developing zero-energy office buildings within the framework of BENG are analysed through an excel model developed for this research.

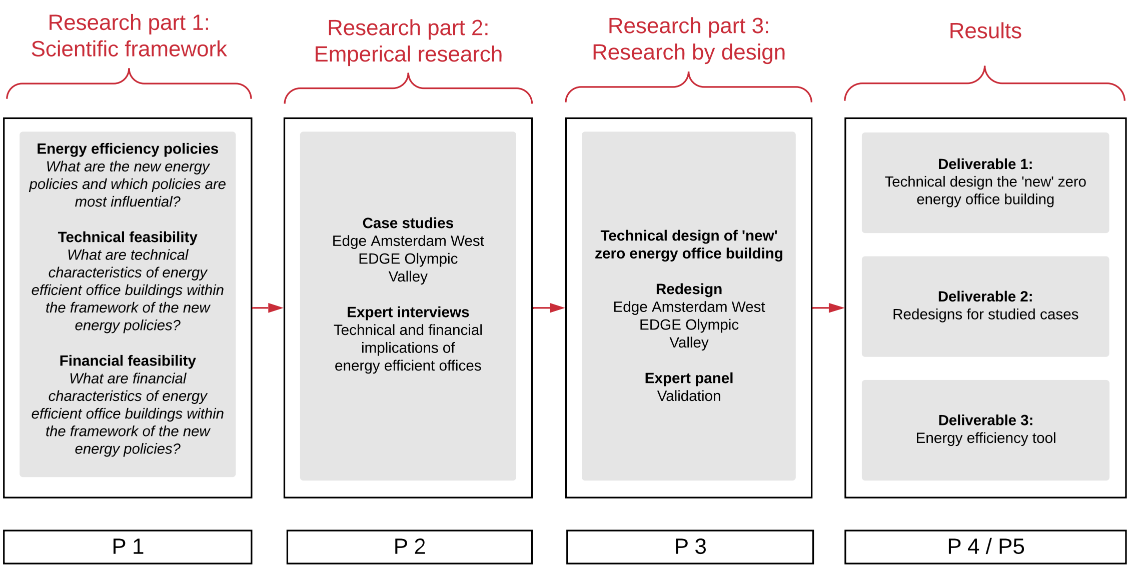

Figure 0.1: Research design (Author, 2020)

Findings

<u>Research perspective 1: policies</u>
The BENG norms and NTA8800 will replace the current EPC norm and NEN7120 determination method in the Netherlands. The BENG norm assures a maximal average energy demand for heating and cooling, maximal average energy consumption, and minimal share of renewable energy for all buildings in the Netherlands, including office buildings. Especially the maximal average energy demand for heating and cooling and the minimal share of renewable energy are an improvement with the current regulations in the Netherlands. With the coming of this new policy, it is not possible anymore to allocate renewable energy generated outside the building plot to the energy performance of office buildings. The current policy energy measures at an area level (NVN 7125) allows for such allocation of energy.

However, it is arguable whether the new regulation BENG and determination method NTA8800 fit the requirements imposed by the Paris Climate Agreement and the EPBD. The current BENG norms do not meet the goals of the Paris Agreement nor the EPBD. The norms for office buildings according to BENG and the Paris Agreement (Paris Proof) for the maximal annual building-related operational energy consumption after netting are:

Paris Proof:	30 - 35 kWh/m^2
BENG:	40 kWh/m^2

These figures illustrate the gap between what the energy performance of the Dutch office stock should be in the near future (2050) and what will become the standard (2021). Buildings that are developed according to the BENG norms will form future problems, as the national building stock of the Netherlands will need to be fully decarbonized by 2050.

Therefore, it can be concluded that national energy efficiency regulations in the Netherlands are still not compatible with international agreements and it is therefore inevitable that they will become stricter in the near future. This thesis proposes a new concept for developers to deal with the BENG norms: *policy independency. Policy independency* is not striving for the minimum requirements imposed by policy but exceeding them in such a way that it makes the policy itself become irrelevant.

<u>Research perspective 2: Technical feasibility</u>
From the studies cases, it became apparent that the majority of the renewable energy supply of current zero energy office buildings is generated outside of the building plot. This method is not compatible with the new energy efficiency policies BENG and NTA8800. Two out of three studied cases would not have been able to be built with their current (technical) designs within the framework of the new policies. None of the cases are zero energy when only the energy supply on a building level is taken into consideration. Only one case is currently considered Paris Proof. Furthermore, when cases are valued with the current and new policies, the valued energy performance changes drastically. The case which is valued with as the least energy-efficient according to current policies is the only case that is still a zero-energy office building according to the new policies.

By redesigning the renewable energy supply of the cases from off-side allocation to vertically oriented Building Integrated PV (BIPV) on the facades of the buildings all cases can comply with the new regulations and the goals of the Paris climate agreement. However, for developing zero energy office buildings within the framework of new energy efficiency regulations solely changing the energy supply of office buildings is not sufficient. To develop zero energy office buildings within the framework of BENG the energy supply and demand of current zero energy office buildings needs to be altered according to the 'technical design for the 'new' zero-energy office building' prescribed by this thesis. The technical design serves as a guideline and technical briefing for developing zero energy office buildings within the framework of BENG and NTA8800.

The case that is redesigned according to the ‘technical design for the ‘new' zero-energy office building' resulted in a redesign that is considered a zero-energy office building within the framework of the new energy efficiency policies. When energy efficiency is prioritized during the early stages of the development and design process it is therefore deemed technically feasible to develop zero energy office buildings within the framework BENG and NTA8800.

After proofing it is technically feasible to develop zero energy office buildings within the framework of the new policies the boundaries for doing so were analyzed. From this analysis, it became apparent that zero-energy office buildings can consist of max 6 floors, Paris proof office buildings 10-15 floors and BENG compliant office buildings can have infinite floors.

Research perspective 3: Financial feasibility

According to scientific research zero-energy and energy-efficient office buildings have higher market values and gross rental incomes compared to non-energy efficient office buildings. Besides these added monetary values of energy-efficient office buildings, there are several other added values. Investors increasingly set high demands for their investments and they incorporate Socially Responsible Investments into their investment strategies (PRI, 2018). Highly energy-efficient office development propositions are therefore more likely to receive equity from investors. Furthermore, companies increasingly attach importance to their corporate reputation through their sustainable offices. Developers of sustainable offices, therefore, have an advantage over their non-sustainable competitors. Moreover, tenants of energy-efficient office buildings are more likely to renew their rental contract and are more satisfied (PRI, 2018; Eichholtz, Kok, & Quigley, 2010; ING, 2017; van Manen, 2019).

Allocation of energy generated outside of the building plot to the energy performance of office buildings is a high costs effective measure for developers to improve the energy performance within the framework of current regulations according to NVN2125: energy efficiency measures at an area level. For the cases, EDGE Olympic and Valley which were studied during this research, energy generated outside of the building plot and allocated to the energy performance of the building was responsible for 65% to 73% of the total energy supply. The investment costs of this allocation of energy however are only 1% to 2% of the total investment cost.

The complete redesign of the case according to the technical design resulted in an investment increase of approximately 6%. However, the energy generated by BIPV is actually consumed by the building which reduces the operating costs, in contrast to allocation where the generated renewable energy only serves accounting purposes. For the complete redesign, the PV installation has a payback period of less than 17 years. In general, the payback periods for industrial PV on the roof of buildings and BIPV on the facades of buildings is approximately 10 to 30 years. It is therefore deemed financially feasible to develop zero energy office buildings within the framework BENG and NTA8800.

Because of the new regulations, it will become more challenging to develop zero-energy office buildings. This might lead to fewer office buildings in the future that are considered zero-energy, even though their energy performance may be an improvement compared to current office buildings. It may be assumed that the stricter determination of zero-energy office buildings leads to less zero-energy office buildings and due to this increased scarcity, the value of zero-energy office buildings will increase when the BENG regulation becomes effective.

Conclusion

This research concludes that it is technically and financially feasible to develop zero energy office buildings within the framework of the new energy efficiency regulation BENG and determination method NTA8800. However, there are boundaries for developing zero energy office buildings within this policy. When office buildings are developed according to the technical design for the new zero-energy office building a maximum of 6 floors is considered feasible for zero energy office buildings.

The boundaries of developing zero-energy office buildings are formed by the average annual energy demand for lighting and ventilation, as these are the building-related electricity consumers within office buildings. Electricity will always be needed for the operation of these installations. The technical design for developing zero energy office buildings within the framework of BENG and NTA8800 prescribed by this thesis is based on proven technologies and current market standards. For developing zero energy office buildings within the framework of BENG and NTA of more than six floors, market standards need to be adjusted and innovative technologies implemented. An example of such a technology is natural ventilation. To achieve this, investors and users of office buildings need to be educated and involved from early design phases. When an investor demands an office building that is more than six floors and is zero-energy, he or she should be aware of the implications of such a building.

Recommendations

Practice

- Developers should aim to be policy independent and aim for developing zero-energy office buildings
- Developers should understand and design their office buildings according to the energy patterns of different functions within these buildings, match these energy patterns, and thereby create closed energy systems where possible.
- Developers should use the technical design for the new zero-energy office building prescribed by this thesis for developing zero-energy office building when BENG and NTA8800 become effective January 2021.
- Developers should inform and educate clients about the benefits, boundaries, and consequences of developing zero-energy office buildings.

Policymakers

- Policymakers must adjust and tighten and improve the current BENG norms in order to fit the requirements of the Paris Climate Agreement and EPBD.
- Transparency and clarity need to be improved when these adjustments are made to the current BENG norms, thereby decreasing uncertainty for market players.

Future research

- Research on the applicability and stakeholders needed for reusing lower caloric residual energy
- Comparative research on the feasibility of zero-energy office buildings on locations with lower market rents.
- Research on the possible emergence of negative effects, such as draft winds, by implementing hybrid ventilation systems in office buildings, and the willingness of investors to abandon current market standards
- Research on how developers can steer and contribute to the energy-efficient use of (office) buildings.

Discussion

This study proved that it is technically and financially feasible to develop zero energy office buildings within the framework of BENG and NTA 8800. In doing so, it makes a couple of recommendations that are listed in the previous section. The main findings and conclusions, however, need to be further discussed.

This thesis recommends policy independency as a strategy for developers of office buildings. However, there can be identified a 'catch 22' in this policy independency strategy: Developers should aim for being policy independent because policies are going to change over time, and they will likely become stricter in the near future. However, it is impossible to be completely policy independent due to the mere fact that policies change. Policies are political instruments which state how certain things are valued, or not. When, for example, high caloric heat networks are not valued as renewable anymore in the future policies, this would mean a change in practice for the development of office buildings, making it impossible to become completely policy independent.

Furthermore, this thesis recommends policymakers to tighten the norms of BENG to better fit the international frameworks of the Paris Climate Agreement and EPBD. This recommendation is done on the bases of the conclusion that it is already technically and financially feasible to develop zero energy office buildings in Amsterdam. However, gross rent income and market values of office buildings in Amsterdam are the highest in the Netherlands. This increases the financial feasibility. In other parts of the Netherlands office buildings with lower gross rent income and market values, it might not be technically and financially feasible to develop office buildings when these norms are tightened. Open communication and transparency with market actors are therefore needed during this process.

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Definitions & Abbreviations

Nearly Zero Energy Buildings (nZEB)
A nearly-Zero Energy Building (nZEB) according to the European EPBD (2010) is '*a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby;* '

Bijna Energie Neutrale Gebouwen (BENG)
Bijna Energie Neutrale Gebouwen (BENG) is the energy regulation of the built environment in the Netherlands that will become effective January 2021. The direct English translation of Bijna Energie Neutrale Gebouwen (BENG) is Nearly Zero Energy Buildings (nZEB), whether the definition is identical is debatable, and will be further discussed in this thesis. The BENG regulation is derived from the EU's EPBD and the corresponding determination method is NTA8800

Energy Performance Coefficient (EPC)
The Energy Performance Coefficient (EPC) is the energy standard in the Netherlands for all newly constructed buildings until BENG becomes effective the 1^{st} of January 2021. The determination method for the EPC is NEN 7120.

Energy Index (EI)
Energy Index (EI) is a required label in the Netherlands for housing associations when they let or sell housing or commercial real estate until BENG becomes effective the 1^{st} of January 2021. All excising offices buildings in the Netherlands need to have at least energy level C from 2023. The determination method for the Energy Index is NEN 7120.

Energy Label
Energy Label is a required label in the Netherlands for private homeowners when they are letting or selling their property until BENG becomes effective the 1^{st} of January 2021. The determination method for the Energy Label is NEN 7120.

Green building certificates
Green building certificates are voluntary certificates that provide proof a building is of a certain sustainability standard. Examples of green building certificates are BREEAM, LEED, Green Star and Energy Star. The assessment criteria vary between different certificates, but the energy performance of the building always plays a large role. In the Netherlands BREEAM-NL is the most used green building certificate.

(Net) Zero Energy Building (NZEB)
A Net Zero Energy building is a building where the net operational energy consumption of the building is equal to the renewable energy generation on-site. The operational energy consumption is the amount of energy that is required for heating, cooling, ventilating, hot water and lighting a building on an annual basis.

Net zero carbon building
A net zero carbon building is a building where the net operational energy consumption if the building is equal to the renewable energy generation on-site and/ or off-site. The operational energy consumption is the amount of energy that is required for heating, cooling, ventilating, hot water and lighting a building on an annual basis.

Renewable energy
Energy that is generated from renewable sources. The main renewable energy sources are solar energy, thermal energy, bioenergy, hydro energy, tidal energy, wind energy and geothermal energy (Boyle, 2004). The possibilities for on-site energy generation for office buildings can essentially be subdivided in four categories: energy generation through solar energy, geothermal energy, biomass energy and wind energy (Yuan, Wang, & Zuo, 2013).

Primary energy (PE)
According to the European Union (2010) primary energy is energy from renewable and non-renewable sources that has not been altered or transformed by humans.

Technical feasibility
Technical feasibility is the degree to which a strategy, program, project or change is Technically possible and attractive.

Financial feasibility
Financial feasibility is the degree to which a strategy, program, project or change is financially possible and attractive.

Building envelope
The building envelope is the interface between the building and the outdoor environment.

Gross Floor Area (GFA)
The Gross Floor Area (GFA) of a building is the total floor area inside the building the building envelope in square meters [m^2]. The Dutch definition of GFA is Bruto Vloeroppervlak (BVO)

Lettable Floor Area (LFA)
The Lettable Floor Area is the floor area of a building that is lettable to tenants in square meters [m^2]. The lettable floor area is typically a percentage of the GFA, and a developer aims is to maximize this percentage. The Dutch definition of LFA is Verhuurbaar Vloeroppervlak (VVO)

Usable Floor Area (UFA)
The Usable Floor Area is the floor area of a building that is used for energy efficiency calculations of buildings in square meters [m^2]. It is a percentage of the GFA. The Dutch definition of UFA is Gebruiksoppervlak (GO)

Paris Proof
According to the Dutch Green Building Council (DGBC, 2019) office buildings meet the requirements of the Paris Agreement (United Nations, 2015) when their total energy consumption is below 50 $kWh/m^2/year$. This is the maxium for both the building-related and the user-related energy consumption. When only the building related energy consumption is considered the maximum is between 25 and 30 $kWh/m^2/year$.

Disclaimer

The numbers in this thesis are formatted according to the Dutch standard. This means that commas are used to separate full numbers from decimals, and points are used to separated 1000's. For example: two thousand and twenty and a half is noted as 2.020,50 in this study.

I. INTRODUCTION

1. Introduction

1.1 Problem identification

There has been a political and societal movement happening for more than a decade. In 2006 Al Gore released his film and book: *An inconvenient truth: The planetary emergency of global warming and what we can do about it.* With this film the whole world became familiar with the problematization of global warming. In his film Gore (2006) describes the consequences of and the cause for global warming. The main cause for global warming being the human-generated greenhouse gases such as CO_2 (Gore, 2006). Several years later the views of Gore (2006) and the majority of scientists have been adopted by most western countries. In 2015 the Paris Climate Summit brought the United Nations together to challenge global warming and climate change. The agreement reached at the conference aims to keep the average global temperature rise below 2° C (United Nations, 2015). To do so all nations had to make big changes within their national policies and regulations, also in the Netherlands. The Dutch national government presented the Dutch climate agreement (Klimaatakkoord) in 2019, stating that the Netherlands is aiming to decrease its CO_2 emissions with 49% compared to the emissions in 1990 (Dutch House of Representatives, 2019).

Each sector in the Netherlands has to contribute to minimising the effects of global warming and climate change, and so does the building sector. Derived from European directives, national policies are implemented to renovate and improve the energy efficiency of the building stock (European Commission, 2019). The national policy on (energy efficient) buildings in the Netherlands goes by the name of BENG (EPG, 2018). All newly built buildings in the Netherlands must meet the requirements of Bijna Energie Neutrale Gebouwen (BENG), which translates to 'Nearly Zero Energy Buildings' (nZEB). The current starting date of this regulation is the 1st of July 2020 after the earlier starting date of January 1st was postponed (Lente-akkoord, 2019). BENG replaces the old Energie Prestaties Coefficient (EPC). According to Van der Heide, Vreemann & Haytink (2016), in their study on the BENG requirements commissioned by the Rijksdienst Voor Ondernemend Nederland (RVO), it will be more difficult to meet the new requirements for some building categories such as buildings higher than five floors, with an emphasis on offices. A change in the BENG policy compared to the current EPC standard is that energy generation outside of the own plot can no longer be added to the energy balance of the building. This is a technique that is currently often used in the development of energy neutral office buildings. This change in policy will make the development of energy neutral office buildings increasingly difficult to accomplish. This change in policy by the government aims to encourage the innovation of new techniques for energy generation on a local level and lower energy consumption of buildings. Before this policy, it was possible to allocate energy generated within a radius of 10 km of the building to the energy balance of a building. (Ollongren, 2018) By buying photovoltaic panels and placing them on the roofs of surrounding buildings or a nearby meadow, a better energy performance could be obtained for the building. Moreover, it is not yet completely transparent what the exact guidelines and requirements of BENG will be and what implications and consequences BENG will bring.

1.2 Problem statement

For the development of office buildings, the political and regulatory changes mean a tremendous change in practice. The implications of BENG will make the current way of developing office buildings difficult and this puts stress on the sector, especially on developers of sustainable and zero energy office buildings. The research side of this thesis will explore the implications of BENG and its effect on the development of zero energy office buildings.

2. Research Questions

2.1 Main research question and goal

The goal of this thesis is to provide insights on how zero energy office buildings can be developed within the framework of new energy efficiency regulations in the Netherlands. These policies sparked a change on developers' ways of operating and the question of which buildings are suitable for zero energy (re)development. Therefore, the main research question of this thesis is:

How can zero energy office buildings be developed considering new energy regulations?

2.2 Research sub questions

To have a grasp on the research question it is dissected into three separate parts. Each part of the research will provide information necessary to conduct the next part of the research and each part will have its coinciding research sub questions.

Research part 1: 'Theoretical framework'
What are the new energy policies and which policies are most influential?
What are technical characteristics of energy efficient office buildings?
What are costs and benefits of energy efficient office buildings?

Research part 2: 'Empirical research'
How are excising zero energy office developments valued according to current and new regulations?
What are the technical characteristics of office buildings that are considered zero energy according to current regulations?
What are the costs and benefits of office buildings that are considered zero energy according to current regulations?

Research part 3: 'Research by design'
Can zero energy office buildings be developed by only changing their renewable energy supply?
How can zero energy offices be developed within the framework of new energy regulations?
What are the boundaries for developing zero energy office buildings within the BENG framework?
What are the costs and benefits of developing zero energy office buildings within the framework of new energy regulations?

2.3 Conceptual model

For the purpose of this thesis a conceptual model is presented in figure 1. The conceptual model is a simplification of the causal system studied in this thesis. It can help the reader to better understand the subject of this thesis. The changes in policy of BENG and the Dutch climate agreement influence the way developers of office buildings operate. Especially on a technical and financial level changes will occur. As a result of these changes in the way developers operate a new, energy neutral office building will have to be realized. As a validation of the process the results of the new energy neutral office building can be compared with the political intentions which sparked the change in policy to begin with.

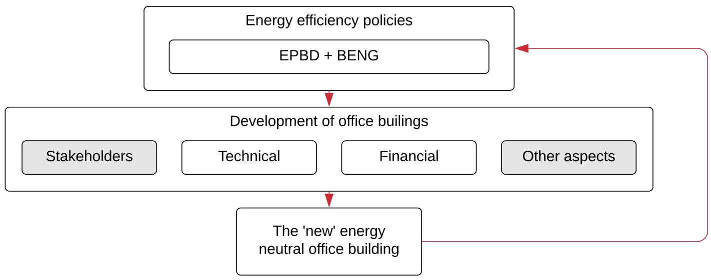


Figure 1: Conceptual model (Author, 2019)

3. Scope definition

The BENG policy and other building regulating policies in the Netherlands have an effect on all buildings. However, because buildings are built in a function specific way it is beyond the scope of this thesis to research the effects of these policies on all different kinds of building types. Therefore, this thesis will focus on office buildings. Office buildings are often multiple floor buildings, which are targeted as buildings that will experience the most difficulties complying with the new regulations (Van der Heide, Vreemann & Haytink, 2016). Offices can be categorised into place, space and use typologies but in essence an office is any place where office work is executed (Dobbelsteen, 2002). For the purpose of this thesis offices in business districts of Amsterdam, without large surrounding plots, will be considered the research subjects as these offices presumably will experience the largest difficulties due to the new policies. This is because office buildings typically are vertically orientated, with the roof surface being relatively small compared to the floor area of these buildings, resulting in relatively little space for the production of energy on the roof.

The research in this thesis will take one step further than complying with the BENG norms and will also focus on how zero energy office buildings can be developed within the BENG framework. In the conclusions of research topic 1 the extensive reasoning is formulated on why this angle is chosen but in short it is because the building energy regulation landscape is highly unstable, and regulations are set to become stricter in the near future.

For the energy demand of office buildings this thesis only takes the energy needed for the building itself into account, so it is not occupant dependent what the energy use of the building is. This is according to the international standard EN 15603:2008 (CEN, 2008). The term zero energy (office) building is often used in literature and also often with different meanings. For the purpose of this thesis the term is used with the following definition: Zero energy (office) buildings are buildings where the operational primary energy consumption consists of the energy needed for heating, cooling, ventilating, lighting, warm water and (de)humidification of the building, on an annual basis.

This angle is chosen so it is in accordance with the energy regulation BENG and the European Union's EPBD. These regulations only refer to operational energy and do not take into consideration other aspects of the life cycle energy of buildings such as embodied energy and demolition energy. Furthermore, for energy efficiency calculations of office buildings for energy regulations such as BENG only the building-related energy is considered. Because the framework of this thesis is shaped by the BENG energy regulation, only the building-related operational energy of office buildings is considered in this thesis.

Lastly, for the purpose of this thesis, Zero Energy and Energy Neutral have the same meaning.

4. Added value of research

4.1 Relevance

Societal relevance
The economies of developed and industrialised countries are almost completely dependent on the energy that is currently available and affordable. This energy currently mainly comes from fossil fuel sources such as natural gas, oil and coal. The built environment accounts for almost 40% of total energy consumption in the European Union and worldwide (Eurostat, 2016; Nejat et al., 2015). The majority of this energy is electricity, produced by the processing of fossil fuels, which generates CO_2 as a by-product. CO_2 that comes into the atmosphere contributes to global warming and climate change. 36% of the EU's CO_2 emissions are produced by the built environment (Eichhammer et al., 2011). The built environment as a heavy polluter needs to improve its management of energy use. The bright side of this problem is that the built environment shows a large potential for improvement. For multiple years technology has been on the market to make the built environment completely energy self-sufficient. It is up to us, the people, to make this change happen. However, the best way is to make this happen is still uncertain. This research explores the possibilities of energy efficient office buildings within the boundaries of new energy efficiency building regulations, thereby giving a glance at the 'new' office building of the future.

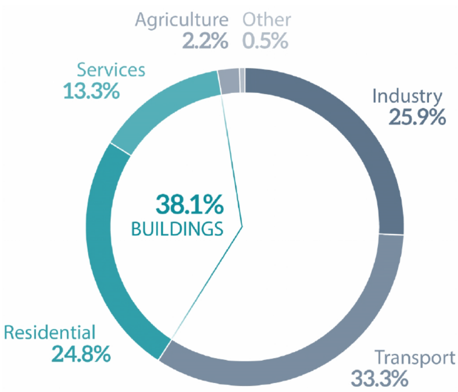


Figure 2: Energy consumption by sector in the European Union in 2014 (EPRS, 2016)

Scientific relevance
The building regulatory landscape of the Netherlands and the European Union has been the subject of several scientific studies. Arnoldussen et al. (2016) researched the impact of the current energy mandatory energy label C for all office buildings in the Netherlands and compared this to what would happen to the technical measures, investment costs, energy savings, payback period if the mandatory level would be A and the implications for the stakeholders. Arnoldussen et al. (2016) focussed on the owner's perspective and aimed to provide insights on whether larger investments with a longer payback period in the energy system of office buildings is more beneficial for owners than multiple smaller investments over time. The results show a positive return on investment and substantial energy savings for the total Dutch office stock.

The norms of the new regulation BENG, the Dutch implementation of the EPBD, have changed multiple times since the regulation was announced and only since the 11th of June 2019 the definitive norms have been presented in a letter to parliament (Ollongren, 2019). Due to the relatively recent nature of the BENG norms there is almost no scientific research on how BENG will influence the Dutch market and its actors. Research that has been published was performed by consulting market actors such as Van der Heijde, Vreemann & Haytink (2016) commissioned by the RVO. Their study looks into energy efficiency building implementation options that are suitable for BENG. They also state that especially office buildings will experience more difficulties meeting the requirements of BENG. Problem with the prior researches in this field is that the norms that were used during the research have changed since the research was published, thereby making the research less reliable.

Since the final norms for BENG were presented in June 2019, and therefore finally can be evaluated, a next step can be made which is analysing the implications on market players. Currently, research on the effects of energy policies on market players is often executed from the real estate investment perspective as is the case with Arnoldussen et al. (2016) and Geerts (2019) who look into the benefits of going label A or nZEB compared to the obligatory label C. Although real estate investor and developer are closely intertwined in practice, both can have different motivations that sometimes can be the opposite of each other. There is no direct scientific research on how BENG will change current practice for developers of office buildings in the Netherlands, while developers are presumably affected most by BENG. BENG can be seen as a regulation directly affecting developers and indirectly affecting investors as developers are the ones who build according to the new regulation and investors pay for the expenses of the new regulation.

There is extensive scientific research on technical aspects of energy efficient office buildings. The energy performance of each building depends to a large extent on the building envelope, as this is the interface between the building and the outdoor environment. Raji, Tenpierik and van den Dobbelsteen (2016) have conducted a research on energy-saving solutions for the envelope design of high-rise buildings in temperate climates through a case study. Conclusions of this study are that that specific design elements can save up to 40% of energy use for high rise office buildings. Other studies such as the research on cost optimal and nearly zero energy building solutions for office buildings of Pikas, Thalfeldt and Kurnitski (2014) show similar results. Next to this there is a growing scientific interest in the optimisation of energy management. This applies to the built environment but also to other sectors.

The scientific knowledge gap that will be filled by the knowledge produced during this thesis is how new regulations will impact the current development practice of office buildings in the Netherlands and what the optimal ways will be for developers to operate within the boundaries of this regulation. BENG will become the new standard minimum energy requirement for new offices and offices that undergo major renovations, but how will BENG impact the development of office buildings that have the ambition to be completely zero energy? These two energy ambitions will be analysed and optimized minding the new energy efficiency regulations. The proposed methodology of this thesis can be used for further scientific research, market players and governmental institutions for setting up energy systems for office buildings.

Applicability in practice
The findings of this thesis will be of value for many different actors in practice. As stated earlier there are a lot of developments around policies for energy efficient buildings. For the people and companies that are dealing with these policies this means a lot of uncertainty. This thesis is written from the developer's perspective, but its products are insightful for many other market actors such as investors and consultants. For public actors this thesis can be seen as a small peek into the future, of what the effects of their policies will be on the development of office buildings and if it will have the desired effect. Finally, this thesis will provide insights in the sustainable office developments of the future, which is of interest for any audience that has affinity with the built environment.

Personal motivation
By doing this research I aim to become an expert on new regulations and their effect on the development of sustainable and energy neutral office buildings. By doing so I aim to provide insights on the future of the development of energy neutral office buildings.

4.2 Research output

This thesis will provide three independent deliverables that each approach the research problem and question from a different perspective.

The first deliverable will be a technical design for the development of the 'new' zero energy office building, within the framework of the new regulations. This design will be a specification of requirements or 'brief' on how an office building can become Zero Energy or BENG compliant. This thesis is written during a graduation internship at the developer EDGE Technologies and this technical design will be implemented into the 'blueprint' of EDGE Technologies, which is currently used as their guideline for developing office buildings.

The second deliverable will be fictive redesigns according to the technical design prescribed by this thesis for three excising cases of zero energy office buildings. These redesigns will clarify where the obstacles are between the current and new regulations and test the feasibility of developing zero energy office buildings within the framework of the new regulations.

The last deliverable is a tool which can be used for evaluating the technical and financial feasibility of developing zero-energy, Paris Proof or BENG compliant office buildings. This tool can be used by developers to develop a quick indication of the energy efficiency potential of a certain design for an office building.

5. Research Method

5.1 Research design and type

The research is divided into three successive parts. The parts are based on the research questions that are presented in the *research questions* section of this chapter and in figure 3. This structure of the research is necessary because the information gathered in the previous section is essential for the next section of the research. For example, the financial feasibility of BENG compliant and Zero Energy office buildings cannot be studied without the findings of the study on the technical feasibility, and the technical feasibility cannot be studied without the findings on how developers can best deal with the new energy regulating policies. The silver lining throughout this thesis is the main research question of this thesis: *How can zero energy office buildings be developed considering new energy regulations?*

The different research techniques used during this thesis are used alternately and in a holistic manner. As can be seen in figure 3 literature reviews, case studies, expert interviews and an expert panel are used alternately.

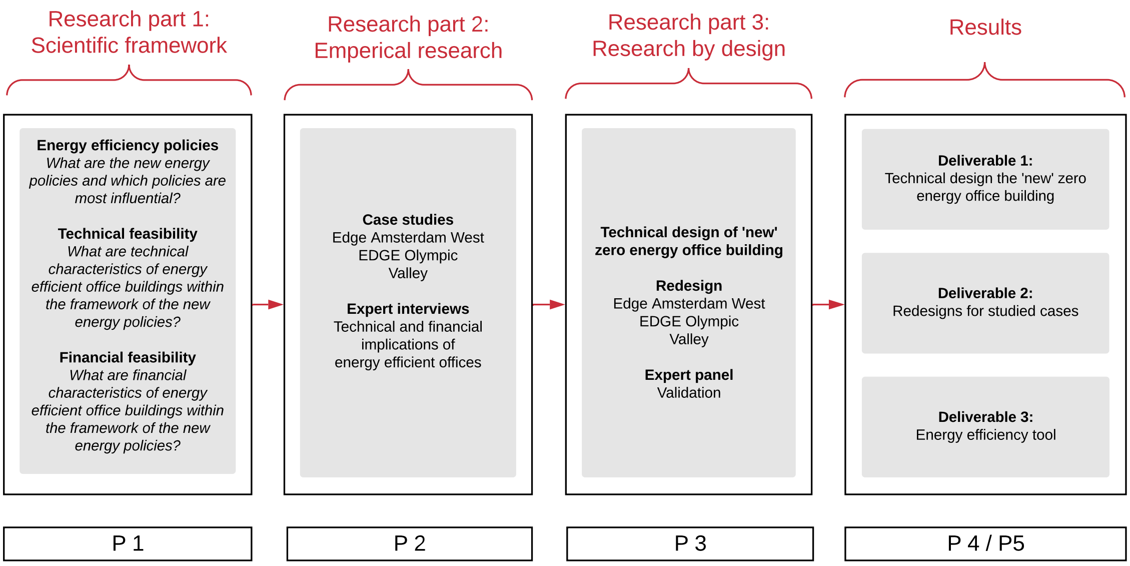


Figure 3: Research design (Author, 2019)

For this thesis an inductive research is conducted, using mixed methods. The first two parts of this research are empirical studies and the third part of this thesis is a research by design. Because the BENG norms are relatively recent in nature and there is little scientific research on how BENG will influence the market and its actors an explorative study is executed for the first and second part of this thesis. The goal of an exploratory research is generating analytically derived conclusions about the group, process, activity or situation studied. After this the researcher transforms these conclusions or generalizations into a grounded theory, thereby explaining the object of study. For an explorative study both quantitative and qualitative data can be collected, but in most explorative studies qualitative data is predominant (Stebbins, 2001). The third part of this research consist of a research of design which uses the findings from the first two parts to fill the knowledge gap. The sub research questions of the first two research parts are predominantly "what is" instead of "how can" questions with the goal of understanding the situation, thereby producing knowledge. These are aspects of an empirical research (Binnekamp et al., 2014).

The third part of this thesis is a research by design. In this part the main research question will be answered. The main research question is an operation-related question because it is a "how can" instead of "what is" question. The aim of the research is creating an instrument which improves the current practice. These are aspects of an operational research (Binnekamp et al., 2014).

5.2 Data collection

Several methods and techniques are used for the collection of data during the research of this thesis. The methods and techniques are described in the following section. The first part of the research of this thesis will provide a scientific framework on the subject. It is common with a thesis to conduct a literature research to review all the relevant current literature and check where the gap in current scientific knowledge is. After the literature research has been conducted conclusions will be made (Bryman, 2016). For each topic mentioned in the sub research questions literature on the subject will be studied. There will be literature studies on international and national building regulations with an emphasis on BENG, a literature study on technical aspects of energy efficient office buildings and on strategies for making office buildings BENG compliant and Zero Energy and lastly a literature study on the financial costs and benefits of offices that are BENG compliant or Zero Energy. All the information gathered through the literature reviews on the different subjects is meant to narrow the scientific knowledge gap and improve the knowledge on the subjects of the researcher.

Next to the data collected through literature review, case studies on current zero energy office buildings are performed to collect qualitative data. This is done for two reasons. Firstly, it gives insights on how the zero energy office buildings currently are constructed and how their energy systems operate. Secondly, these case studies are needed to pinpoint where the current practice and the new regulations of BENG collide. It is expected that the new BENG regulation and the current way of developing zero energy office buildings will not go hand in hand. For the case studies on Zero Energy office buildings developments of the developer EDGE Technologies are used.

Lastly data is collected through interviews with experts in the field of sustainable buildings and office valuation experts. The interviews will be conducted with sustainability consulting companies on the technical implications of BENG for office buildings in the Netherlands.

5.3 Data analysis

The data collected during this research is predominantly qualitative data. The quantitative data that is collected and analysed during this thesis comes from scientific literature. Literature reviews summarize all the results and conclusions from previous research which gives the researcher and reader an overview of the current scientific status of the subject. For subjects where the scientific research is scarce other sources are consulted. This is the case with the review of the European and Dutch policies with an emphasis on BENG. Here the literature consulted consists mainly of governmental documents due to the absence of scientific literature. On the technical and financial aspects of zero energy office buildings substantial scientific research is available. The findings of the literature reviews are evaluated and categorized and at the end of each chapter and preliminary conclusions are drawn which give direction for the rest of the thesis.

For the case studies on zero energy office buildings the method of Yin (2014) is used. According to Yin (2014) case studies are used as a method to describe a phenomenon in a real-life context. For the purpose of this thesis the phenomenon studied in cases is the energy systems of zero energy office buildings. According to Yin (2014) there are three steps for executing proper case studies. For the analysis of case studies first individual case reports are written. Secondly cross-case conclusions need to be drawn. For the purpose of this thesis cross conclusions with findings of literature review also need to be drawn. All the results of the literature review and case studies will be presented to an expert panel to confirm the reliability.

II. SCIENTIFIC FRAMEWORK

6. Policies

On several governmental levels energy policies for buildings are implemented to improve the overall energy performance of buildings in the regions where these policies are effective. These policies are not completely separated but are often intertwined or derived from each other. In this section the energy policies on European and national level are evaluated.

6.1 The United Nations: Paris Agreement & Paris Proof

In 2015 the United Nations formed the Paris Agreement. The aim of the Paris Agreement is to keep the average temperature rise on earth below 2 °C by reducing the total amount of CO_2 emissions of the 180 participating countries (United Nations, 2015). The built environment is a large contributor to the emission of greenhouse gasses and is responsible of approximately 40% of the total energy consumption in the European Union (EPRS, 2016).

In order to make the built environment 'Paris Proof' the total energy consumption of the built environment in the Netherlands should be reduced with two thirds compared to the current average. (Dutch Green Building Council, n.d.). The Dutch Green Building Council (DGBC) (2017) did a study on what the necessary changes for the built environment are in the Netherlands in order to meet the goals of the Paris Climate Agreement. The DGBC (2017) did calculations assuming on what the energy demand of buildings in different sectors should be in 2050, assuming that in 2050 all consumed energy in Netherlands should be generated from renewable sources. Because all energy should be generated from renewable sources the total amount of energy that is available is less than it currently is, which means that buildings can consume considerably less energy than they do now.

In order for office buildings to be Paris Proof, and the Netherlands to meet the goals of the Paris Agreement, the calculations of the DGBC (2017) show that the maximum energy consumption of office buildings cannot exceed 50 kwh/m^2/year. If this energy consumption is exceeded, along with other sectors, the energy demand of the Netherlands cannot be generated completely from renewable sources in 2050.

This maximum energy consumption of 50 kwh/m^2/year includes both the building-related energy consumption and the user-related energy consumption of the building and takes the energy balance of the building into account. In other words, the energy demand of the building after the local production of renewable energy has been taken into account. When only the building-related energy is considered for determining whether an office building is Paris Proof the standard that should be considered is 30 - 35 kwh/m^2/year for the building related energy consumption (DGBC, 2019).

6.2 European Union: EPBD & EED

The European Union (EU) has set policies as legislative instruments to promote the improvement of the energy performance of buildings within the EU. The Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive are the two main legislative documents to promote the energy performance of buildings and to boost renovation within the EU (European Commission, 2019). The ambitions of the EU on the energy performance of buildings are specified in the Energy Performance of Buildings Directive (EPBD, 2018). The main statements of this directive are that all new buildings in the EU must be nearly zero-energy by 2020 and the need for member states to establish strong long-term renovation strategies, aimed at decarbonizing the national building stocks by 2050 (EPBD, 2018). The definition of a nearly zero-energy building according to the European Union is a building that has a very high energy performance and the (nearly zero) amount of energy that is consumed should be significantly generated by renewable energy sources (European Union, 2010). The implementation into national law of these policies is up to the national governments of the countries of the European Union. This freedom for member states of the EU to implement the EPBD in their national policies is because not all countries are seen as equally able and capable to meet the same standards. Factors such as climate and financial capabilities are very different per country and therefore have an influence on how and when standards can be met. EU countries have until the tenth of March 2020 to implement the provisions of the EPBD into national law (European Commission, 2019). The EPBD (2010/31/EU) has been operational since 2010 and has resulted in a positive change in the energy performance of buildings within the EU. Since the EPBD buildings in Europe consume only half as much as typical buildings from the 1980s (European Commission, 2019).

The European Energy Efficiency Directive (EED) of 2016 pleads for the decrease in overall energy consumption and sets to increase energy efficiency throughout the European Union. For the EED energy efficiency is the most cost-effective way to support the transition to a low carbon economy and to create growth, employment and investment opportunities. The EED set a binding energy efficiency target of 20% in 2020 and an energy efficiency target of 30% for 2030. By setting these targets the EED aims to give EU countries a long-term perspective to plan their national policies, strategies and investments accordingly (European Commission, 2016).

6.3 National policy developments

The Netherlands, as a member state of the European Union, is obliged to establish regulations and policies to promote cost-effective renovation and energy efficiency improvement of their building stock (European Union, 2018). A complication of the EPBD policy is that it is not very compatible with the existing energy labels in the Netherlands. The current (voluntary) national labels do not fit in the framework of the EPBD (Mlecnik, 2013). This resulted in a number of new agreements and regulations. In table 1 an overview is given of the current and future regulatory instruments for energy efficiency of buildings.

Standards / requirements	Building type	Applicability	Determination method
EPC	New constructions	Current building standard until the BENG becomes effective in (presumably) 1st of January 2021.	NEN 7120
EI (Energy Index)	New constructions & existing buildings	Required label when selling or letting by housing associations or commercial real estate. All offices need to have at least energy level C from 2023.	NEN 7120
Energy Label	New constructions & existing buildings	Required label for private homeowners when selling or letting their property.	NEN 7120
BENG	New constructions	Effective from January 2021, compatible with the EPBD.	NTA 8800

Table 1: Overview of the different standards and determinations methods in the Netherlands (RVO, n.d.-a; RVO, n.d.-b; RVO, n.d.-c)

As can be seen in table 1 there are currently many different standards for different types of buildings and/ or ownership situations. The EPC is the current building standard for energy efficiency for new constructions and is in accordance with the Dutch Building Decree (RVO, n.d.-a). The Energy Index (EI) and Energy Label are required labels when selling or letting a property. For housing associations and actors operating in the commercial real estate market this is the EI, for private homeowners this is the Energy Label. An extra addition to the EI is the obligation for offices to be at least energy label C by 2023, resulting in an Energy Index of 1.3 (Ollongren, 2018). All three standards use the same determination method: NEN 7120. This method, however, is not compatible with the EPBD. Therefore, there will be a new building standard and determination method which is compatible with the EPBD: BENG and NTA 8800 which will become effective from the first of January 2021.

Energy measures at area level (EMG)
Since 2012 it is possible in the Netherlands to have renewable energy that is generated off-site allocated to the energy balance of a building according to the legislation "Energiemaatregelen op Gebiedsniveau" (EMG) which translates to energy measures at area level. The following energy measures can be used to determine the EPC according to the NVN 7125 (EMG):

- External heat supply through district heating & cooling can be added to the energy performance (EPC) of a building, reducing the total energy demand for heating and cooling (RVO, n.d.).
- Electricity that is generated within a 10 km radius of the building from renewable energy sources, such as solar energy and wind energy, can be allocated to the energy performance (EPC) of a building as the generation of renewable energy (RVO, n.d.).

This legislation is often used in practice, especially for the development of larger utility buildings such as office buildings, in order to achieve a higher energy performance of the building and to meet requirement of green building certificates (C. Berning, personal communication, September 21, 2019).

Subsidies
Besides energy efficiency regulations there are several energy subsidies in the Netherlands which promote sustainable energy generation and energy efficient buildings.

<u>SDE+</u>
First of all, there is the SDE+ subsidy in the Netherlands, which stands for Stimulering Duurzame Energie (Stimulation of Sustainable Energy). This subsidy aims to make investments in solar panels feasible and profitable by contributing government funding to the business case of solar installations that qualify for the subsidy. Each year there is a spring round and an autumn round where civilians and companies can hand in their business plans, and the government divides the subsidies between qualified participants. The last round of SDE+ subsidy will be in spring 2020 and has a budget of two billion euros (BREEAM-NL, n.d.; RVO, n.d.)

<u>SDE++</u>
After the last round of the SDE + subsidy it will be replaced by the SDE++ subsidy (Stimulation Sustainable Energy transition). With the SDE++ other renewable energy sources besides solar energy also can apply for government funding. Besides renewable energy generation, active CO2 reduction also qualifies for SDE++ subsidy. The following five themes can apply for subsidy (PBL, 2019; PNO Consultants, 2019):

- Electricity generated from renewable energy sources
- Renewable heat and green gas
- Small-scale renewable heat (ISDE)
- Advanced renewable fuels for transportation
- CO_2 reduction in industry.

A large difference of the SDE++ subsidy compared to the SDE+ subsidy is the way subsidy requests are ranked and approved. With SDE+, the subsidy requests are ranked on the amount of renewably generated electricity in kWh. With SDE++, the subsidy requests are ranked on the amount of CO_2 that is reduced in tons (PNO Consultants, 2019).

This is a large difference because CO_2 reduction is deemed to be more cost-efficient compared to the renewable generation of electricity from solar or wind energy. With CO_2 reduction the CO_2 is taken out of the air and stored on land. This characteristic of SDE++ would mean less government funding for the renewable generation of electricity.

6.4 BENG

Determination method: NTA 8800
The NTA 8800 will become the determination method for all types of buildings, newly built and renovated. The determination method assesses the energy efficiency of buildings through three indicators (RVA, n.d.-a) called BENG 1, 2 and 3:

1. *The maximum energy requirement in kWh per Usable Floor Area (UFA) per year.*

This indicator is about limiting the energy demand of the building itself. This is the amount of energy needed for heating, cooling and ventilation. The building envelope, orientation, compactness and ventilation system are an important factor for this indicator (EPG, 2018).

This first indicator is new compared to current determination methods. With the NEN 7120 a building could achieve a high energy efficiency rating even though it was consuming a lot of energy by generating enough renewable energy. This is not possible anymore with the NTA 8800 and according to EED ambitions (European Union, 2016).

2. *The maximum primary energy consumption in kWh per UFA per year after netting.*

The second indicator is the amount of energy there is needed per m^2 UFA per year to heat and cool the building, produce warm water, ventilate the building and regulate air humidity. The efficiency of installations, low temperature heat emission, short-circuit hot water and heat recovery and the application of renewable energy are important factors for this indicator (EPG, 2018). The amount of renewable energy that is supplied in kWh / m^2 per year is subtracted from the total consumption, leading to of BENG 2.

3. *The minimal share of renewable energy in percentages.*

The last indicator is the percentage of renewable energy of the total energy consumption of the building. When BENG 2 has a value of zero this results in a BENG 3 value of 100%. An important addition to this indicator is that the allocation of electrical energy generated outside of the building plot cannot be added to the energy performance of the building as was the case with the NVN 7125 (EMG). The supply of residual heat and cold though heat grids is still considered (RV,n.d.,g).

Norms: BENG
BENG consists of three requirements for the indicators of NTA 8800. Also called BENG 1, 2 and 3. These requirements will be applied for all newly built buildings from January 1st, 2021 (Lenteakkoord, 2019). This is in accordance with the EPDB, stating that all new buildings need to be nearly zero-energy buildings from the 31th of December of 2020 (European Union, 2010). An important addition to this rule is that these requirements also apply for buildings that undergo major renovations or transformations. In the EPBD it is specified what is understood by 'major renovations.

According to Article 2:10 of the EPBD 'major renovation' are renovations of buildings where (European Union, 2010):

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

Member States of the European Union may choose to apply option (a) or (b) (European Union, 2010). For the Netherlands a 'major renovation' (Dutch: ingrijpende renovatie) is defined as a renovation where more than 25% of the of the surface of the building envelope is renewed, changed or enlarged RVO (n.d.-e). This means option b is applicable in the Netherlands, and that any office renovation or transformation that radically changes the building envelope must adhere to the requirements of BENG.

On the 11th of June 2019 a new revision of the BENG requirements was proposed by the Dutch minister of foreign affairs in a letter to parliament. In this letter the definitive requirement of BENG are published. An overview of the different versions of the BENG norms for office buildings is given in table 2.

	BENG 1 **Energy requirement** **[kWh/m².yr]**	**BENG 2** **Primary fossil energy consumption** **[kWh/m².yr]**	**BENG 3** **share renewable energy** **[%]**
2015 - NEN 7120	≤ 50	≤ 25	≥50
2018 - NTA 8800	A_{ls}/A_g ≤ 2,2 ->90 A_{ls}/A_g > 2,2 ->90 + 50 * (A_{ls}/A_g -2,2)	50	≥30
2019 - NTA 8800	A_{ls}/A_g ≤ 1,8 BENG 1 ≤ 90 A_{ls}/A_g> 1,8 BENG 1 ≤ 90 + 30 * (A_{ls}/A_g -1,8)	≤ 40	≥30

Table 2: Developments regarding BENG requirements for offices. A_{ls}= Enveloppe Surface [m2], A_g = GFA [m2]. (Ollongren, 2019; RVO, n.d.-d; Lenteakkoord, 2018).

So with the current and final norms of BENG all office buildings that are newly build or undergo major renovations need to have an energy requirement of less than 90 kWh/m².yr when the ratio between the envelope surface and UFA is less than 1,8, and less than 90 kWh/m².yr + 30 * (A_{ls}/A_g -1,8) when the ratio between the envelope surface and UFA is greater than 1,8. The primary energy consumption after netting needs to be less than 40 kWh/m².yr and the percentage of renewable energy consumption of the total energy consumption of the building needs to be at least 30%.

Something that becomes apparent is that although BENG literally translates into nZEB (nearly Zero Energy Buildings), these norms of the BENG are not as the EU defines nZEB buildings (European Union, 2010):

"a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent from renewable sources, including sources produced on-site or nearby."

This definition allows for some free interpretation, but a minimum of 30% renewable energy of the total energy consumption does seem to be in line with "*a very significant extent".*

This being said, another observation of BENG compared to earlier regulations such as the EPC which can be considered an improvement is that with BENG and the NTA 8800 determination method a poor bioclimatic design cannot be compensated by adding highly efficient installations and (off-site) renewable energy generation. This is due to BENG 1 which ensures that the buildings envelope is of high quality, with for example good insulation and glazing with high thermal resistance.

In addition to this, it must be noted that BENG compliant office buildings are no compliant with the goals of the Paris Climate Agreement and are therefore not 'Paris Proof'. The maximum building-related energy requirement of BENG compliant office buildings is 40 kWh/m².yr and for Paris Proof buildings the maximum building-related energy requirement cannot exceed 25-30 kWh/m².yr. Furthermore, the Paris Proof calculations of the DGBC (2017) only allow for netting with renewable energy produced on plot, the supply of energy through heat networks which is weighed with the NTA8800 is not weighed.

6.5 Policy independency

With the continuous changing of the norms of the BENG regulation, the unclarity on the determination method NTA8800 and the question when the calculation tool will be available for testing, it may be concluded that the Dutch building regulating landscape is highly unstable, and there is no certainty that the current 'final' BENG requirements will remain the requirements until January 2021 when the BENG presumably becomes effective. This fact creates a high level of uncertainty for market players, especially for the developers of office buildings. Therefore, to answer the research question: "*How can developers best deal with these new policies?",* a new terminology is proposed: *policy independency*.

Policy independency is not striving for the minimal requirements imposed by a policy but exceeding them in a way the policy itself becomes irrelevant. In the case of BENG this means developing Zero Energy offices instead of BENG compliant offices. This is because when an office is a Zero Energy Building it also is BENG compliant, but this is vice versa not the case. By being *policy independent* market players such as developers take matters into their own hands, thereby excluding the uncertainty created by the policies and regulations. Therefore, this thesis will research how to develop Zero Energy office buildings, within the framework of the BENG regulation where renewable energy generation only can happen on site. Furthermore, the Netherlands committed to the Paris Climate agreement, stating that its built environment will be completely decarbonised by 2050. BENG compliant buildings will not result in a completely decarbonised building stock. This means that the current norms have to be tightened relatively soon in order for the Netherlands to comply with the Paris Agreement.

The term Zero Energy Building (ZEB) is used often in literature and can have very different definitions. Marszal et al (2011) did a research on the different definitions for ZEBs and categorised them by the following aspects: (1) metric of balance, (2) period of balance, (3) type of energy use, (4) type of balance, (5) renewable supply options (6) PE & CO_2 factors and (7) unique factors. The definition of a Zero Energy office building for this thesis will be given in the following chapter '*Technical feasibility'* in the '*Energy in the built environment'* section.

Beside the benefits discussed above of being policy independent, it is assumed that there are other financial benefits for being policy independent. These benefits and the costs that come with it will be evaluated in the '*Financial Feasibility'* chapter of this thesis.

There is an obvious challenge in the 'policy independent' strategy: developing Zero Energy office Buildings, where renewable energy generation is only done locally, is a bigger challenge than developing offices that are BENG compliant. Therefore, this thesis will also look into the implications of BENG on the development of office buildings.

7. Technical feasibility

The technical feasibility is the degree to which zero energy office buildings are technically possible. This chapter presents a theoretical framework on the technical feasibility of zero energy office buildings in the framework of current and new regulations.

7.1 Energy in the built environment

Before moving on to strategies on how to design and optimise energy systems of office buildings a framework for energy in the build environment is presented. The umbrella energy concept in the built environment is Life Cycle Energy, which consists of three types of energy: *embodied energy, operational energy* and *demolition energy* (Emmanuel & Baker, 2012).

The embodied energy of a building is the amount energy that is needed for extracting, processing, producing and suppling the materials from which the building itself is constructed. The energy needed for the construction of the building is embodied energy, but also the energy needed for maintenance and refurbishment of the building is considered embodied energy. The latter two that are also referred to as *recurring energy* (Emmanuel & Baker, 2012; Hammond, & Jones, 2008). The operational energy of a building is the amount of energy needed to heat, cool, ventilate, light and power a building. The amount of energy that is required for demolishing and disposing of a building when it's on the end of its lifespan is considered the demolition energy (Emmanuel & Baker, 2012).

The operational energy of a building is commonly called the energy consumption of a building. The energy consumption of a building consists of two types of energy: the building-related energy consumption and the user-related energy consumption. The energy needed for heating, cooling, ventilating, lighting, warm water and (de-) humidification is considered the building-related energy. All other operational energy needed of an office building, such as energy needed for laptops, computer screens, electrical vehicles, elevators, etc. is considered user-related energy (DWA, 2019; DGMR, 2019). In reality it is difficult to completely separate the building- and user-related energy due to the interaction between a building and its users (Blom, Itard, & Meijer, 2011)

Energy regulations such as BENG and the European Union's EPBD refer to operational energy and do not take into consideration other aspects of the life cycle energy of buildings such as embodied energy and demolition energy. Furthermore, for the determination of energy efficiency of (office) buildings for energy regulations such as BENG only the building-related energy is considered. Because the framework of this thesis is shaped by these energy regulations, only the building-related operational energy of office buildings is considered in this thesis.

7.2 The energy step strategies

Trias Energetica

A method for structuring an energy-efficient design is the three-step strategy 'Trias Energetica'. This strategy was developed by Duijvestein in 1979 which was derived from an earlier three-way-model introduced by Lysen 1996 (Brouwers & Entrop, 2005). The strategy itself is quite simple and effective. It consists of three measures which could be implemented in the building industry to increase the energy-efficiency of buildings. The step that is most favourable is placed first and the least favourable is placed last. When looking at energy efficiency problems this particular sequence needs to be followed in order to gain the maximum results. The steps of Trias Energetica according to Duijvestein (1996) are:

1. Minimize the energy demand of the building.
2. Maximize the use of sustainable energy sources to meet the remaining energy demand of the building.
3. If there is a remaining energy demand after step one and two, use fossil energy sources as efficient as possible.

The determination method of BENG, the NTA 8800, works with similar the steps of the steps. The major difference is that the second and the third step are swapped, making the order 1: energy demand (1), 2: Fossil energy consumption (3) and 3: share renewable energy (2). Why this is changed does not become evident but for the BENG determinations the order does not matter. For the Trias Energetica on the other hand, it is essential to follow the steps in the correct order. (Duijvestein, 1996; Ollongren, 2019)

The New Stepped Strategy
Van den Dobbelsteen (2008) states that although the Trias Energetica had the right intentions, it has not brought the built environment to the desired sustainable state since it was published more than twenty years ago. Problems of the Trias Energetica are that market actors often (deliberately) mistake the intentions of the steps by stating their product decreases the energy demand of the building while this is not the case (Van den Dobbelsteen, personal communication, 11 December 2019) and the early introduction of the renewable energy sources, which are often a more expensive solution than lowering demand. These aspects of the Trias Energetica do not encourage building designs with a minimal energy demand (Van den Dobbelsteen, 2008).

The steps of the New Stepped Strategy are similar to the steps of the Trias Energetica. The main difference is that the Cradle to Cradle principles of McDonough and Braungart (2010) have been integrated into the strategy. The main principle of Cradle to Cradle is that all cycles should be closed and that all waste should equal food, which is also the basic principle for circularity and a circular economy (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). This thesis focuses on the energy efficiency of office buildings, but the principle of closing energy cycles is something that should be considered when making buildings that are highly energy efficient. In the New Stepped Strategy circularity and energy efficiency meet each other. The additions to the New Stepped Strategy compared to the Trias Energetica are in bold, the final step that is left out is underlined and between brackets. The steps of the New Stepped Strategy are (Tillie, et al., 2009):

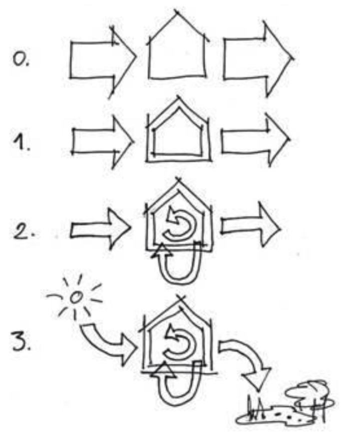


Figure 4: 'New Stepped Strategy' (van den Dobbelsteen, 2008)

0. The unsustainable starting situation
1. Reduce the energy consumption of the building by using intelligent and bioclimatic design.
2. **Reuse waste energy streams**
3. Use renewable energy sources **and ensure that waste is reused as food.**
4. <u>(Supply the remaining demand cleanly and efficiently)</u>

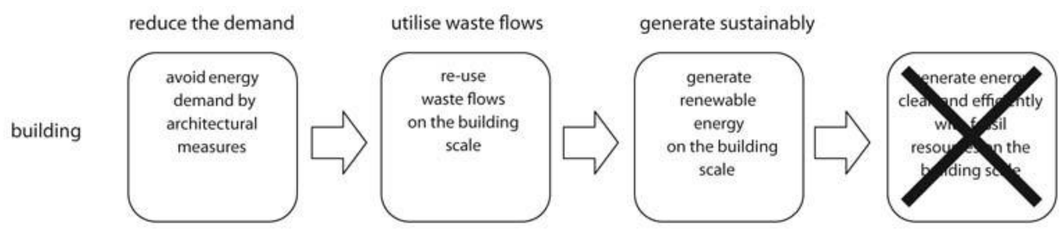


Figure 5: 'New Stepped Strategy' (Tillie, et al., 2009)

Step four is something that will be needed the coming years but, in the future, this simply will no longer be possible and desirable (Tillie, et al., 2009). This fourth step makes the true distinction between Zero Energy and energy efficient buildings. According to the energy efficiency strategies that have just been discussed the first step for making energy efficient office building is minimizing the energy demand of office buildings. The next section will explore the possibilities on energy saving solutions for office buildings in the Netherlands by using the steps of the New Stepped Strategy. Afterwards different solutions for generating renewable energy for the remaining demand will be explored.

The New Stepped strategy can be implemented on the level on individual buildings, but the effectiveness of the strategy increases when implemented on an urban level. Especially the second step of the strategy: *reuse of waste energy* can provide large solutions for the built environment which are currently not utilised. Literature states that 40%-50% of the demand for heat in urban areas can be reduced by optimally utilising residual heat and cold flows (Tillie et al., 2009; Kürschner et al., 2011).

7.3 Reduce consumption

The first step of the New Stepped Strategy is probably the most important one and is equal for both the step strategies: *Minimize the demand*. (Duijvestein, 1996; Van den Dobbelsteen, 2008). The first step mainly refers to passive design measures that do not need extra energy. Essential aspects of reducing demand are smart and bioclimatic design strategies, which can be defined as a "design approach that deploys local characteristics intelligently into the sustainable design of buildings and urban plans" (Van den Dobbelsteen & Van der Linden, 2007). According to the Köppen-Geiger classification (2006) the Netherlands is classified as Cfb which stands for a warm temperate oceanic climate, fully humid precipitation and mild warm summer temperatures. The average annual temperature is 10 degrees in the Netherlands. Due to this climate buildings in the Netherlands are heating dominated. Minimising heat losses and maximising solar heating are therefore key elements in making Zero Energy Buildings in the Netherlands.

EDGE Technologies has commissioned a study by DWA and DGRM on the impact of the new requirements on buildings BENG (EDGE, 2019). EDGE Technologies develops buildings according to the EDGE Blueprint. This is an extensive program of requirements with the purpose of ensuring modern, attractive, sustainable and healthy offices. The purpose of this research (EDGE,2019) was to determine measures which can further reduce the energy consumption of the Blueprint buildings and give an impression of the BENG compatibility of Blueprint buildings.

This study showed that for the EDGE blueprint buildings the largest energy consumers are artificial lighting and ventilation. This can be explained by the integration of thermal energy storage systems (TESS) incorporated into the blueprint. This TESS allows relatively energy-efficient cooling and heating. Figure 6 illustrates the energy consumption of EDGE blueprint buildings (Blue).

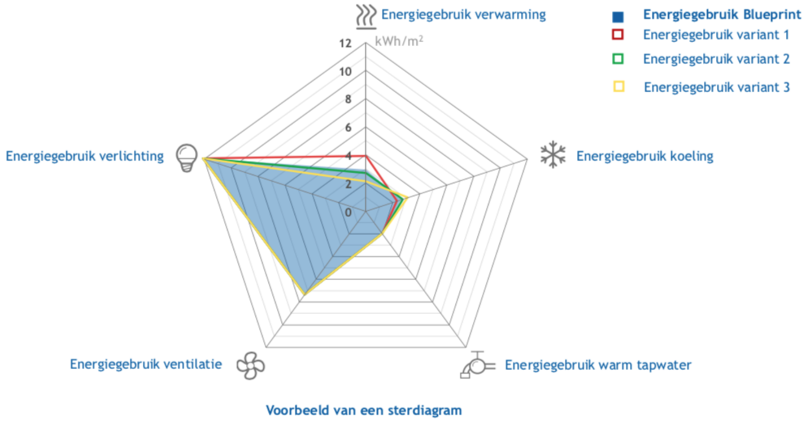


Figure 6: Star chart showing the division of energy consumption for EDGE Blueprint office buildings. (EDGE, 2019)

According to these two sources the energy demand of office buildings seems to be mainly composed of lighting, ventilation and heating and cooling. By incorporating a heat and cold storage system with the office building relatively efficient cooling and heating can be achieved. This information suggests that the largest energy demand reductions are to be won in lighting and HVAC.

The energy demand of a building depends to a large extent on the design of the building envelope. Assessing energy-saving solutions for the envelope design of office buildings is therefore crucial in lowering energy demand. Raji, Tenpierik and Van den Dobbelsteen (2016) have conducted a research on energy-saving solutions for the envelope design of high-rise office buildings in temperate climates through a case study. The main findings of their research are:

- For high-rises, optimisation of design elements can save up to 40% on energy use.
- The optimum window-to-wall ratio is around 50% for East and West orientations in temperate climates.
- For a Double Skin Facade (DSF) building, blinds perform better when placed outside the cavity.
- A summer operation schedule is preferable to adjustable shadings in cold climates.
- Adding a green roof to a well-insulated roof hardly influences energy consumption.

The four measures selected for optimizing the energy performance of the building envelope in this research include glazing type, window-to-wall ratio, sun shading and roof strategies. By taking the base case as a reference and optimising one parameter at each step, this study resulted in a high-performance envelope design that offers a considerable energy-saving of around 42% for total energy use, 64% for heating and 34% for electric lighting. Goia (2016) did a research on optimal Window-to-Wall Ratios for different climate in Europe. For the Dutch Cfb climate the following WWRs are optimal for minimizing the energy use for heating, cooling and lighting:

- North facing facades WWR = 43% (39%-45%) Energy saving potential = 19%
- East facing facades WWR = 39% (37%-41%) Energy saving potential = 20%
- South facing facades WWR = 40% (38%-44%) Energy saving potential = 13%
- West facing facades WWR = 41% (39%-43%) Energy saving potential = 18%

Another option for lowering the energy demand of office buildings is making use of natural ventilation. In a study by Raji, Martin, Tenpierik, Bokel & Van den Dobbelsteen (2019), six natural ventilation scenarios were developed for the base design and the CFD package in Design Builder was used to predict their flow pattern under two summer conditions. Natural ventilation strategies can provide comfortable conditions for up to 90% of the occupancy time in summer and therefore can save a significant amount of energy that is generally needed for the operation of traditional mechanical ventilation and air-conditioning systems.

7.4 Reuse of waste of energy systems

The second step of the New Stepped Strategy is new compared to the original Trias Energetica. In the way our current energy system is shaped there is a lot of heat loss from all the primary energy that enters our society and nothing useful is done with the waste products. In this system a lot of primary energy is wasted because certain primary energy media are used in situations where their energy potential is not necessary. An example of this is a gas flame of 1.500 °C which is used for residential functions where this high caloric thermal energy is not needed. A more sustainable system would be the low-caloric system, where waste heat is used to heat low grade functions such as households (LowEx, 2004). This system would require significantly less energy and could be up to six times better than the current energy system (Van den Dobbelsteen, Gommans & Roggema, 2008). The reuse and recycle step of the New Stepped Strategy can be divided into 4 different categories: *Attuning, Exchanging, Storing and Cascading*.

Attuning
Attuning is the collective of the next three categories. With attuning the built environment attunes its programme and function of its buildings to the way they can interact with each other. So, in a building with mixed functions such as office and residential the example of exchanging can be used where heat is exchanged from office to residential functions. The functions within buildings and between buildings need to be attuned so the energy supply can used as efficiently as possible (Tillie, et al., 2009).

The techniques for reusing waste energy described in this section are scalable and work on a building, neighbourhood, district and city level. The potential increases when larger areas are considered for the reuse of residual energy flows. Especially with large facilities such as swimming pools, shopping centres and ice rinks the energy pattern is so specific that by combining these a lot of energy can be saved.

Exchanging
Exchanging of energy can be done inside a building between functions and with other buildings in the area with a different pattern of energy requirement. An example of exchange: because of the internal production of heat the average office buildings currently start cooling when outdoor temperature is higher than 12 °C. When the outdoor temperature is 12°C residential buildings still need to be heated. This characteristic of office and residential buildings provide opportunities for heat exchanging (Tillie, et al., 2009).

Storing
The storing of energy can be achieved by storing electricity, heat and cold. Heat and cold are only abundant when there is little demand for them. For the best energy balance heat and cold need to be stored during the season they are available in excess and used in the season they are scarce. Storing should only be done when exchanging is not required because the energy loss is larger when the energy is stored (Tillie, et al., 2009). Thermal Energy Storage Systems (TESS) are often used in practice to reuse waste energy flows.

Cascading
Cascading energy occurs when excess heat is transferred from one medium to another. This can happen inside buildings by for example the excess heat of an oven to produce warm water or on an area scale an example is the passive solar energy captured by greenhouses which normally is lost into the air. With a heat exchanger this waste stream could be captured and used to heat homes. If all the waste energy streams at area level are used optimally it then becomes possible to see if primary energy can be generated sustainably. Although solar panels, solar collectors and heat pumps with ground collector systems can be installed in each individual building, it is much more economical to set these up at an area level (Tillie, et al., 2009).

7.5 Generate from renewable sources
Using renewable energy sources is absolutely necessary because without it, sustainable development will never be successful (Van den Dobbelsteen, 2002). According to the BENG norms all generation of renewable electrical energy must happen on site. There are several renewable energy sources that can be used for the generation of electricity or other forms of usable energy such as heat. In this section the different renewable energy sources and corresponding energy generating techniques are discussed. The main types of renewable energy are solar energy, thermal energy, photovoltaics, bioenergy, hydro energy, tidal energy, wind energy and geothermal energy (Boyle, 2004). The possibilities for generating energy on site for office buildings can essentially be subdivided in four categories: energy generation through solar energy, geothermal energy, biomass energy and wind energy (Yuan, Wang, & Zuo, 2013).

Solar energy
Energy generation through solar energy is the most frequently used in the built environment. The generation can be achieved through photovoltaic panels which generate electricity from solar energy or through solar thermal collectors which generate heat from solar energy.

Photovoltaic panels

The energy provided by the sun is one of the most important renewable energy sources and it has been used to generate electricity for several years (Jayakumar, 2009). Photovoltaic panels (PV), commonly known as solar panels, are used in the built environment on the roofs and facades of buildings. Recently, building integrated PV is a way of replacing traditional building materials by PV materials which generate electricity in parts of the building envelope. PV panels consist of PV cells which are thin rectangular wafers, normally with 10cm x 10cm dimensions (Fouad, Shihata, & Morgan, 2017).

The amount of electricity produced by PV panels is dependent on the availability of sun and the characteristics of the site where the panel is located (Mondol, Yohanis, & Norton, 2007; King, Boyson, & Kratochvil, 2002). Approximately 40 years ago during the large-scale commercialisation of PV panels the efficiency of the PV panels was well below 10% and expensive (Kalogirou, 2004). Currently 20% of the solar energy that is collected is converted into electricity is still a very limited portion. The remaining majority of the solar energy is converted into heat (Fouad, Shihata, & Morgan, 2017). A problem with this is that the efficiency of the panel for the generation of electricity goes down when the temperature of the panel rises (Zoheir Haghighi, personal communication, December 2, 2019). There are experimental PV cells and panels which have efficiencies of more than 30% but these are not yet commercialized on a large scale and therefore expensive (Kalogirou, 2004). According to the BENG norms only the energy generated by PV panels within the borders of the building plot can be allocated to the energy balance of the building. Before the BENG norms become effective it is possible to generate renewable energy within a radius of 10 km of the building plot in the Netherlands. With this system buildings can achieve a Zero Energy status for national legislation and green building certificates such as BREEAM-NL (RVO, n.d.,g). In the Netherlands this is common practice with office buildings and subsidised by the national government (SDE+) (RVO, n.d.,c).

Solar thermal collectors

Solar thermal collectors are a less commonly known but a more efficient way of converting solar energy into useful energy in buildings. Solar thermal collectors are heat exchangers that transform solar radiation energy into heat and transfer this heat into a fluid which is circulating through the solar thermal collector. Commonly air, water or oil run through the collector. The energy that is collected by the circulating fluid is transferred to hot water which can be used to heat the building or moved to a thermal energy storage where the energy can be used when needed (Kalogirou, 2004).

PVT

There has also been large academic interest in the combination of PV and solar thermal collectors which is called Photovoltaic/Thermal (PVT) technology. The basic idea is a combination of PV and solar thermal components which result in a system/technology that produces both heat and electricity (Zondag et al., 2005). The last 40 years substantial academic research has been conducted on PVT technology and since 2000 there appears to be larger interest and international participation but application in real projects is still limited (Chow, 2010).

Geothermal energy

Geothermal energy is another renewable energy source. Geothermal energy is stored in the earth and can be harvested with the use of Geothermal Heat Pumps or Ground Sourced Heat Pumps (GCHP). The heat pump technology is popular in the build environment and is applied often, also without geothermal energy sources. (Yuan, Wang, & Zuo, 2013; Ozgener, Hepbasli, & Dincer, 2006). Geothermal energy is used in practice but can only effectively be applied in larger areas due to the subtraction of hot water and injection of cold water into the ground surface in different locations. By using geothermal energy, the energy needed for the heating and cooling of office buildings can be greatly reduced. Systems that use geothermal energy are thermal storage systems and heat pumps. These systems increase the energy-efficiency of the heating and cooling of buildings.

GSHP

Ground Sources Heat Pumps (GSHP) use the interior of the earth as a source for heat. When the technology is used for the heating of buildings a fluid is used to transfer heat from the interior of the earth to the surface thereby using geothermal energy. The transportation fluid is often water. GSHP can also be used to cool buildings when excess heat of the building is transferred to the interior of the earth, using it as a heat sink (Sanner, Karytsas, Mendrinos, & Rybach, 2003).

Biomass energy

In literature biomass energy is often considered a renewable energy source because of its renewable nature: plants and organisms will (presumably almost) always grow. Biomass energy can refer to any source of energy produced by biological materials that are non-fossil. Examples are firewood, livestock manure, ethanol produced from corn or sugarcane and industrial organic waste (Yuan, Wang, & Zuo, 2013; Kumar, Kumar, Baredar, & Shukla, 2015).

<u>CHPG</u>

Within office buildings small-scale and micro-scale Combined Heat and Power Generation (CHPG) are a way of harvesting renewable energy from biomass. The CHPG technologies that are compatible for the use in office buildings are *Reciprocating engines* and *Fuel cells* according to Alanne and Saari (2004). Because small-scale CHP technologies are not fully commercialized yet operational experiences for extended periods are not yet available.

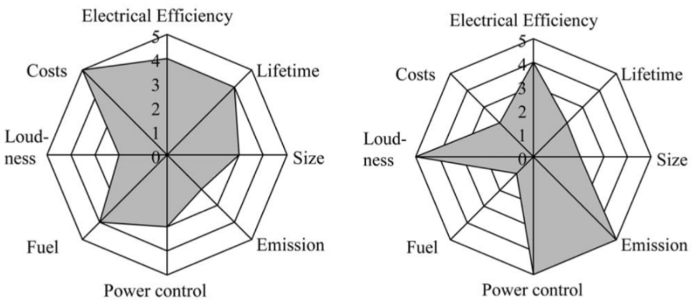


Figure 7: Performance of small-scale CHP technologies *Reciprocating engines (left)* and *Fuel cells (right)* (Alanne & Saari, 2004).

A problem or negative aspect of biomass energy is that although it is considered renewable, it contributes to global warming and climate change due the carbon dioxide (CO_2) that is released when the biological materials are burned. This characteristic of releasing greenhouse gasses occurs with fossil fuels. Another issue with Biomass energy technologies is that they are not self-sufficient. The biological materials that serve as the fuel for the CHPG technologies need to be delivered to the building, which itself is energy consuming. Furthermore, other unwanted emissions occur during the burning of biomass such as nitrogen.

Biomass energy does look like it will become an effective renewable energy source according to the NTA8800 determination methods and BENG norms. DGMR (2019) advises implementing biomass-fired boiler plants (BMBP) for the generation of heat in office buildings in order to comply with the BENG regulations.

Biomass-fired boiler plants (BMBP) generate heat from Biomass energy. There are three basic biomass fuels: pellets, chips and shreds. For office buildings the optimal biomass fuel are pellets (Koppejan, 2016). In general, BMBP is a less preferable solution for the production of renewable energy than PV due to several reasons:

- It can be perceived as less sustainable/renewable
- The release of CO_2 and other non-greenhouse gasses such as nitrogen
- Complex logistics for the delivery and storage of Biomass

If an office building has a total heating demand of more than 0.8 PJ a bio boiler greater than 500 kW can be justified. The number of full load hours would be 2,821 per year. In table 3 the data on the costs and energy production of BMBPs is illustrated (Koppejan, 2016). In general, only when the reuse of thermal residual energy from heat networks or thermal energy storage systems are not an option, BMBP should be considered a solution for the supply of renewable energy.

Biomass	Medium	Cost price [€/kWh]	Avoided costs [€/kWh]	Unprofitable top [€/kWh]
A1 pellets	Water	0,093	0,052	0,041

Table 3: Data on Biomass fired boiler plants for office buildings (Kloppejan, 2016).

Wind energy
Finally, energy can be generated from wind. The generation of electrical energy from wind energy is not frequently used in practice due to the difficulties arising from urban environments, where wind cannot blow freely. The amount of energy generated by wind turbines is also not substantial on smaller scales (Rezaie, Esmailzadeh, Dincer, 2011).

Renewable electrical energy generation and grid connection
For office buildings that generate electrical energy through one of the renewable sources discussed earlier, a connection to the electricity grid is common in the Netherlands. In the Netherlands the vast majority of energy generation that happens on building plots happens through PV. Two basic types of PV application can be identified: stand-alone systems and grid connected PV systems. Stand-alone systems are used in areas where there is no electricity grid available, which is not the case for office buildings in the Netherlands. (Kalogirou, 2004). During peak production hours the electricity grid can become overloaded, resulting in negative electricity prices. For these hours it can be more effective to store the electrical energy (Verhees, Raven, Veraart, Smith & Kern, 2013)

7.6 Overview of energy strategies within BENG
In this section the step strategies are discussed and checked on their compliance with the BENG regulation. In figure 8 the steps of the New Stepped Strategy are displayed for the different scales on which they can be applied. According to the BENG regulation electrical energy can only be generated on-site. The steps that are surrounded by the red dotted line are not allowed under the BENG regulation.

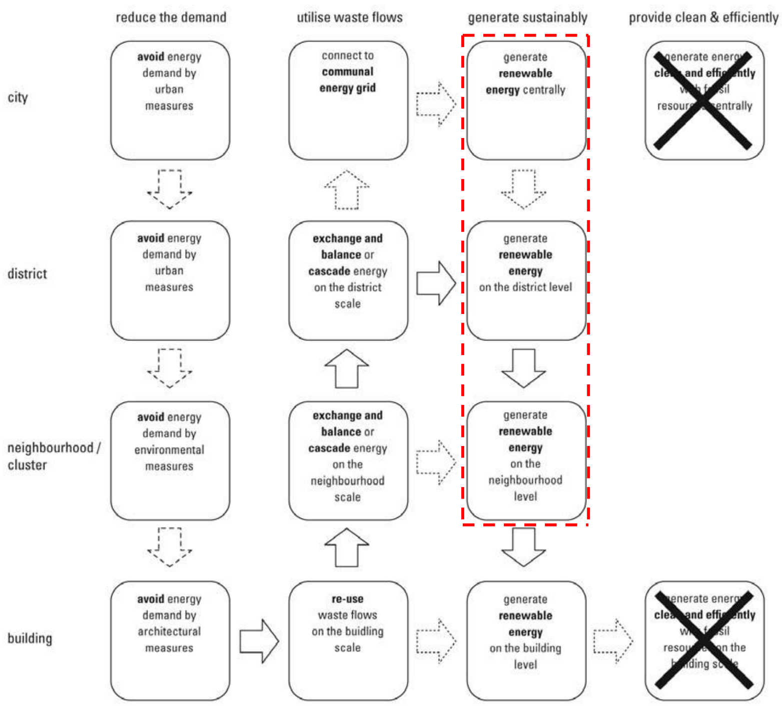


Figure 8: The REAP methodology and its applicability with BENG (Image by Tillie, et al., 2009; modified by author)

Current projects incorporate the Cradle 2 Cradle (C2C) philosophy on a district or urban level. Closing all loops is more effective and sometimes only feasible on a larger scale. BENG has incorporated in the norms that electrical energy should be produced within the borders of the building plot. This contradiction might cause challenges for the development of office buildings.

BENG 1

BENG 1 focusses on the passive energy efficiency measures that can be applied to make office buildings more energy efficient. This can be categorised under smart and bioclimatic design. It is an indicator to measure the energy demand for heating and cooling and is influenced by the characteristics of the building envelope. The following building aspects have an influence on BENG 1: the insulation performance, glazing type and percentage of the facade, infiltration, orientation, shading, sun blinding, natural (summer night) ventilation, compact geometry and thermal mass.

BENG 2

BENG 2 focuses on the efficient use of fossil energy, by looking at the energy use that is required for heating, cooling, ventilation, lighting, hot tap water and de-humidification in kWh/m^2 per year. In essence this translates to the energy efficiency of the installations regulating the mentioned aspects of the building operation. Lastly, BENG 2 is influenced by BENG 3: when BENG 3 is 100% this results in BENG 2 being zero.

BENG 3

For BENG 3 there is no separation made between step two: '*Use of waste of energy systems'* and step three: '*Generate from renewable sources'* of the 'New Stepped Strategy' (Van den Dobbelsteen, 2008). For the BENG 3 norm and the NTA 8800 determination method solar energy, geothermal energy, soil energy, seasonal thermal storage systems (WKO), wind energy, energy from the outside air and (partly) solid biomass are considered renewable sources. In addition, (industrial) residual heat is appreciated in the determination method (DGMR, 2019).

8. Financial feasibility

For this thesis financial feasibility is considered to be the degree to which a new investment is financially possible or attractive. In the Netherlands, the development of office buildings is typically known for developers selling their developments to an investor who will exploit the building through renting out the building or by using it to house their own organisation. This sale purchase agreement can happen before, during or after the construction of the building (Squires & Heurkens, 2014). An important characteristic of the real estate market is that it is a heterogeneous market, with heterogeneous products. There are no identical properties in the eyes of the consumer and this characteristic is caused by the perception and preference of the consumers. The heterogeneous character of real estate makes it difficult to pinpoint the exact costs and benefits of buildings aspects such as the energy system of a building. A problem with the sale and purchase market of office buildings is that it is a non-transparent market and little data is available (Brounen & Jennen, 2009). The number of rental transactions is substantially higher than the number of purchase transactions, resulting in more data on rental prices (Van Gool et al., 2013). Therefore, the rental prices of office buildings are also evaluated during this chapter.

The literature review in the next sections describes the current scientific findings on the costs and benefits of energy efficient office buildings. As mentioned earlier, due to the heterogenetic character of real estate it can be difficult to pinpoint the exact costs and benefits of energy efficiency measures. Moreover, the majority of scientific research focuses on the comparison between certified green buildings and conventional buildings that don't have any green or sustainability certificate. Comparative scientific research on energy efficient and non-energy efficient is less evident. Moreover, the added value of developing energy efficient buildings comes partially from the green building certification that can be acquired, which will be addressed in the section on the added value. Due to the lack of scientific research on the comparison of costs and benefits of energy efficient and non-energy efficient office buildings comparative research on green certified versus non-certified office buildings is also evaluated.

8.1 The costs of energy efficient office buildings

The majority of academic research focuses on the positive effects that energy efficient buildings with green building certificates have. However, a much smaller section of academic research is concerned with aspects that are perceived as negative such as higher construction and investment costs. In this regard the work of Kats, Alevantis, Berman, Mills, & Perlman (2003) and Kats et al. (2010) are the most cited. Furthermore, most studies explore the costs of green buildings from a theoretical perspective instead of testing for cost premiums. Some researchers state that green office buildings have higher incremental costs due to the costs of the process of achieving a green building rating. These costs involve both application costs and the costs of external consultation (Cupido, Baetz, Pujari & Chidiac, 2010).

Author (year)	Cost premium estimation method	Number of green buildings	Building type	Green building cost premiums (%)		
				Good	Very good	Excellent
Rawlinson (2007)	Actual green building costs with green-specific costs itemized	1	Office building	Not studied		2.8
Building Research Establishment (BRE), Centre for Sustainable Construction & Cyril Sweett Sustainability and Cost Consulting Teams (2005)	Actual green building costs against model costs to Building Regulations standards	4	Office building, house and healthcare	0–0.22	0.1–5.7	3.3

Table 4: Summary of BREEAM costs studies in the UK (Rehm & Ade, 2013).

Tables 4, 5 and 6 present summaries of quantitative academic studies on the additional costs of BREAAM, LEED and Australian Green Star (Rehm & Ade, 2013). These studies were conducted in the countries where the green building certificates originated: The United Kingdom, Australia and the United states. The predominant approach in the studies from tables 4, 5 and 6 was to compare the modelled green building costs against the modelled conventional building costs. The studies that used actual building costs data for the determination of green building costs premiums only make up for a small portion of the researches. The research of Matthiessen and Morris (2004, 2007) and Davis Langdon (2009) are the only studies that compared actual green building cost data with actual non green building data. From all the studies conducted by Davis Langdon employees no statistically significant evidence was found for additional costs for green buildings compared to non-green buildings.

From the summaries in tables 4, 5 and 6 it becomes apparent that although some scientific studies found statistically significant green building cost premiums, the independent results of the studies fluctuate considerably.

Author(s) (year)	Comparison method	Number of green buildings	Building type	Green building cost premiums (%)		
				4 Star	5 Star	6 Star
Fullbrook & Woods (2009)	Actual ecological sustainable development (ESD) costs against non-green model costs	1	Generic, fictitious government office fit-out	1.25 (4 Star building) 2.91 (unrated building)	4.37 (5 Star building)	6.23 (5 Star building)
Davis Langdon (2007)	Model green building costs against generic, non-green model costs	1	Generic, fictitious office building	0	3–5	9–11+
Fullbrook (2007)	Model green building costs from developer proposals against non-green model costs	20	Office buildings	3 (Class A) 7 (Class B)	7 (Class A) 15 (Class B)	Not studied
Fullbrook, Jackson, & Finlay (2005)	Actual '*ecologically sustainable development*' costs against non-green model costs	1 1 1 1	Academic building Hospital School Library	−15 (savings) 1.5 5.7 4.9		
	Model ESD office building costs against non-green model costs	1	Office building	Low/medium ESD: 6.5 Medium/high ESD: 11.5		

Table 4: Summary of Australian Green Star costs studies (Rehm & Ade, 2013).

Furthermore, some scientific studies argue that if sustainability measures are implemented integrative and early in the design process, the costs of green office buildings should be less than non-green conventional office buildings. Hydes, and Creech (2000) used two cases to exhibit green buildings that have lower instead of higher initial capital investments. Other studies indicate that higher costs for green buildings compared to their non-green counterparts are a misconception. They state that quantity surveyors aggravate the costs of green measures and undervalue the costs savings (Bartlett & Howard, 2000).

Lastly, many studies that determine construction costs for sustainability measures are conducted by private professional parties rather than academic institutions. Because of this these studies often do not enclose their used methodology, data sources and do not subject their data to relevant statistical tests. The firms that are transparent with their research are firms that are actively involved in green building projects. Such as Davis Langdon (2009).

Author(s) (year)	Cost premium estimation method	Number of green buildings	Building type	Green building cost premiums (%)			
				Certified	Silver	Gold	Platinum
Kats *et al.* (2010)	Survey respondents' (primarily architects) stated '*green premium*' estimates	37	Office buildings	1.20	2.25	3.37	7.66
		29	Schools	0.35	1.00	1.30	9.60
		17	Academic buildings	1.65	1.80	1.93	2.53
Davis Langdon (2009)	Unpaired *t*-test of actual green fit-out costs against 13 non-green fit-out costs	12	Office interior fit-outs	No statistically significant cost difference			
Matthiessen & Morris (2007)	Unpaired *t*-test of actual green building costs against non-green building costs within each building type	17	Academic buildings	No statistically significant cost difference			
		26	Laboratories				
		25	Libraries				
	Unpaired *t*-test of actual green building costs against 22 non-green building costs	15	High-rise apartments				
Nilson (2005)	Actual green building costs with green-specific costs itemized	1	Office building	Not studied		0.82	Not studied
Steven Winter Associates (2004)	Model green building costs against model costs to 'federal design requirements'	2	Office building and courthouse	1.4–2.1	3.1–4.2	7.8–8.2	Not studied
Matthiessen & Morris (2004)	Unpaired *t*-test of actual green building costs against 98 non-green building costs across all building types	45	Academic buildings, laboratories and libraries	No statistically significant cost difference			
Kats, Alevantis, Berman, Mills, & Perlman (2003)	Survey respondents' (primarily architects) stated '*green premium*' estimates	33	Schools and office buildings	0.66	2.11	1.82	6.50
Northbridge Environmental Management Consultants (2003)	Meta-analysis of '*secondary research*' and unspecified analysis of actual cost data	1	Generic, fictitious building	Soft costs: 1.5–3.1 Hard costs: 3–8			
Packard Foundation (2002)	Model green building costs against model 'market' cost	1	Proposed, new office building	0.9	13.1	15.5	21.0

Table 5: Summary of LEED costs studies in the USA (Rehm & Ade, 2013).

8.2 The value of energy efficient office buildings

Compared to the costs of energy efficient office buildings, the added value of energy efficient buildings is something that is more evident in scientific literature. The majority of scientific research concerns the added value of office buildings with green certification compared to conventional office buildings, but there are also studies that focus on the added value of energy efficiency of office buildings. Energy efficient office buildings make for working environments that have lower energy costs, an increase of productivity of employees, a decrease of employee absence and a reputation increase of the company (Fuerst and McAllister, 2011; Eichholtz, Kok, and Quigley, 2010).

Reduced operating costs

The most obvious added value of offices that are energy efficient compared to conventional office buildings is the decrease in energy consumption, resulting in lower energy costs and lower overall operating costs. Energy is responsible for 30% of the total operating costs of typical office buildings according to Eichholtz, Kok, and Quigley (2010), adding that energy costs are the most manageable. Dukers (2004) claims that utility consumption costs make up 10% of the total operating costs of office buildings in the Netherlands. Electricity, gas and water consumption combined are considered the utility consumption costs. These costs are included in the rental price as service costs and payed for by tenants, which make energy efficient buildings interesting for tenants. Bordass (2000) argues that a complication with the decreased operating costs due to decrease of energy consumption is that because commercial office buildings are often multi-tenant with leases that are 'net' of the operating expenses. Because of this the financial benefits of lower energy consuming office buildings are felt by the tenants of the office building rather than the building owner who is responsible for the initial energy efficiency investments.

Increased property values and rental prices
According to a study of ING in collaboration with the university of Maastricht energy efficient office buildings in the Netherlands in 2015 had a higher market value per m^2 of 9.1% and a higher gross rental income per m2 of 11.8% compared to energy-inefficient but otherwise equivalent offices. In 2016, this premium for energy-efficient offices amounted to 8.6% in appraised market value per m2 and 9.9% in realized gross rent per m2 (ING, 2017).

In their research Miller, Spivey and Florance (2008) researched the sale purchase price premiums that were payed for office buildings that were certified with LEED and found that there was an 11% increase compared to non-certified buildings. Another study found that LEED office buildings had a sale price premium of $130 per square foot. (Wiley, Benefield & Johnson, 2010) although it was claimed by Fuerst and McAllister (2011) that Wiley, Benefield and Johnson (2010) did not properly conduct their research. Fuerst and McAllister (2011) did a similar research using hedonic regression analysis and found that LEED certified office buildings had an average rental premium of 4% to 5%. Divine and Kok (2015) performed a hedonic regression analysis on buildings in the USA and Canada with an Energy Star. This label is comparable with the European Energy label. They found that Energy star certified buildings had a 2.7% premium on their rental rates.

A study on the added value of and willingness to pay for energy efficient office buildings in the Netherlands was conducted by van Manen (2019). In this empirical quantitative study, the economics of energy efficient office buildings is studied by combining auction theory and hedonic regression analysis. This method was used as a way to isolate the price premiums paid for the energy efficiency of office buildings.

To quantify the energy efficiency of the studied office buildings van Manen (2019) used the EPI-Index and the Energy labels of office buildings in the Randstad. The Energy Performance Index (EPI) gives the total energy consumed in a building in kWh/m2*yr. The EPI is considered the simplest and most relevant indicator for quantifying the energy efficiency of a building. Secondly, Energy labels are mandatory when letting or selling office buildings in the European union according to different European directives (92/75 / CEE, 94/2 / CE, 95/12 / CE, 96/89 / CE, 2003/66 / CE). Energy labels range from A +++ to G.

In table 7 van Manen (2019) compared average rental prices of office buildings in the Randstad, the Netherlands. Energy label A is accompanied by the highest average rent. Something that stands out is the higher rental price of office buildings with energy label G compared to D, E and F in research of Van der Erve (2011). This can be explained because those buildings are either at an A-location or those with a monumental appearance.

Variabelen	N	Gemiddelde	Mediaan	Std. deviatie	Min	Max
Energie label A	112	207,75	200,00	66,05	98	355
Energie label B	35	164,40	155,00	41,16	92	275
Energie label C	35	181,03	168,00	42,25	110	300
Energie label D	14	167,64	168,00	45,90	95	295
Energie label E	28	141,39	152,50	47,18	64	215
Energie label F	18	148,67	125,00	64,07	88	360
Energie label G	39	169,97	155,00	50,33	102	356

Table 7: Average rental prices per energy label (van Manen, 2019)

Amsterdam is considered the A location for office buildings in the Netherlands, with emphasis on the south axis. In table 8 van Manen (2019) compared the rental prices of Amsterdam of offices with energy label A until G with the average rental prices of the rest of the Netherlands. Here label G scores higher than energy labels B until F, only energy label A scores higher. Another interesting finding is that the rental prices of offices with energy label D for the rest of the Netherlands are comparable with those of Amsterdam, while for the other energy labels Amsterdam generate a high rental price.

Variabelen	Stad	N	Gemiddelde	Mediaan	Std. deviatie	Min	Max
Label A	Overige steden	35	156,94	145,00	26,59	115	236
	Amsterdam	77	230,84	225,00	65,77	98	355
Label B	Overige steden	14	139,86	151,00	24,95	92	175
	Amsterdam	21	180,76	175,00	42,11	125	275
Label C	Overige steden	14	154,79	155,00	19,00	110	198
	Amsterdam	21	198,52	193,00	44,69	115	300
Label D	Overige steden	8	167,63	168,00	20,34	135	205
	Amsterdam	6	167,67	163,00	69,99	95	295
Label E	Overige steden	19	125,84	125,00	46,55	64	185
	Amsterdam	9	174,22	170,00	29,18	125	215
Label F	Overige steden	6	117,33	115,00	18,50	94	148
	Amsterdam	12	164,33	137,50	73,39	88	360
Label G	Overige steden	28	152,39	142,50	25,77	102	227
	Amsterdam	11	214,73	200,00	69,02	145	356

Table 8: Average rental prices per energy label in Amsterdam compared to other cities in Randstad (van Manen, 2019)

Van Manen's (2019) research shows a positive rental premium for energy-efficient office buildings. The results of his research indicate a rent price premium of 8.4% for office buildings with energy label A-C, which are considered energy efficient, compared to office buildings with energy label D-G. Another finding from this research is that tenants pay considerably higher rents for office buildings with a B and or C label than for buildings with energy label A. Tenants of buildings with energy label E are only willing to pay considerably lower rents than for those with label A. Furthermore, this research added a control level for building aesthetics and facade type, which is not evident in other academic research. Would these features have been left out the rental price premium for energy efficient office buildings (label A-C) would have been 13,5% (van Manen, 2019).

Higher occupancy rates, increased chance of lease renewal & increased tenant satisfaction

In their research Devine and Kok (2015) compared energy efficient office buildings with the conventional office buildings and looked for differences in occupancy rates, tenant satisfaction and likelihood of lease renewal. The buildings that were analysed are located in Canada and the USA and the dataset consisted of 12.000 lease contracts, from a total of 300 buildings. Devine and Kok (2015) found that office buildings certified with an Energy Star on average had 9.5% higher occupancy rates compared to non-certified office buildings. For the tenant satisfaction it was found that certified offices scored on average 6% higher than conventional offices and the chance of lease renewal went up for certified office buildings. What must be noted with this research is that the sample sizes can be considered small so all findings should be handled with caution.

Improvement of corporate reputation

Being environmentally aware and responsible is known to enhance a company's corporate reputation. Khanna, van der Voordt and Koppels (2013) studied seven cases where international companies used their corporate real estate strategies as a tool to improve their corporate reputation and identity. The office locations of these companies were used to show the sustainability ambitions of the company to employees and external stakeholders. The real estate management strategy of a corporation is an important aspect of the Corporate Social Responsibility (CSR) of corporations. Eichholtz, Kok, and Quigley (2016) studied 11.000 tenant decisions and found that real estate is an important aspect of a company's CSR.

For investors it is also increasingly important to invest in sustainable real estate. These investments are called Socially Responsible Investments and large international investors incorporated the principles of Socially Responsible Investments into their strategies (PRI, 2018). Real estate funds are rated on their sustainability performance and investments using the Global Real Estate Sustainability Benchmark (GRESB), which is used by 70 major institutional investors. The interest of investors in sustainable real estate is a large driver for developers of office buildings to create office buildings that are highly sustainable and energy efficient.

9. Conclusions theoretical framework

In this chapter the theoretical framework is concluded, and the findings of theoretical framework are presented. For each of the three subjects studied in the theoretical framework the sub-research questions are presented and answers are given. The findings and conclusions presented here form the basis for the continuation of this research.

Conclusions policies
For the policy section the following sub research question was presented:

What are the new energy policies and which policies are most influential?

The BENG norms and NTA8800 will replace the current EPC norm and NEN7120 determination method in the Netherlands. Developers should always comply with the norms stated in this regulation and therefore they have a major influence on the way they operate. Especially the disappearance of the possibility to allocate electrical energy generated renewably outside of the building plot according to NVN 7125 (EMG) will create challenges for developers of office buildings. This change in policy was sparked by the Paris Climate Agreement (United Nations, 2015) and the Energy Performance of Buildings Directive (EPBD, 2018) because the current national energy regulations were not compatible with the framework of EPBD (Mlecnick, 2013).

However, it is arguable whether the new regulation BENG and determination method NTA8800 fit the requirements imposed by the Paris Climate Agreement and the EPBD. By signing the Paris Climate Agreement, the Netherlands committed to the goal of only consuming renewable energy and having a decarbonised building stock 2050. The current BENG norms do not meet the goals of the Paris Agreement nor the EPBD. The norms for office buildings according to BENG and the Paris Agreement (Paris Proof) for the maximal annual building-related operational energy consumption after netting are:

Paris Proof:	30 - 35 kWh/m^2
BENG:	40 kWh/m^2

These figures illustrate the gap between what the energy performance of the Dutch office stock should be in the near future (2050) and what will become the standard (2021). Buildings that are developed according to the BENG norms will form future problems, as the national building stock of the Netherlands will need to be fully decarbonised by 2050.

Therefore, it can be concluded that it is inevitable that these norms will have to become stricter in the near future in order to meet the goals of the Paris agreement and EPBD. This thesis proposes a new concept in order to deal with the BENG norms: *policy independency. Policy independency* is striving not for the minimal requirements imposed by a policy but exceeding them in such a way that it makes the policy itself become irrelevant. In the case of BENG this means developing Zero Energy offices instead of BENG compliant offices.

Conclusions technical feasibility
For the technical feasibility section, the following sub research question was presented:

What are technical characteristics of energy efficient office buildings?

The technical characteristics are presented by the individual norms of the BENG regulation: BENG 1, BENG 2 and BENG 3.

<u>BENG 1</u>
The value of BENG 1 is determined by the annual energy demand for heating and cooling office buildings in kWh/m^2. By using Smart and bioclimatic design strategies the value of BENG 1 can be significantly reduced. The following building aspects have an influence on BENG 1:

- Insulation performance
- Glazing type and percentage
- Air tightness
- Building orientation
- Shading elements
- Natural ventilation
- Compact building geometry
- Thermal mass

<u>BENG 2</u>
The value of BENG 2 is determined by the total annual energy consumption of office buildings per m^2 after netting with the production of renewable energy by the BENG 3 standard. The total annual energy consumption is the energy required for heating, cooling, ventilation, lighting, hot tap water and de-humidification. The following building aspects have an influence on BENG 2:

- HVAC installations
- Lighting installations
- Warm water installations
- Renewable energy supply (*BENG 3*)

<u>BENG 3</u>
The value of BENG 2 is determined by the amount of renewably generated energy on the building plot and the reuse of residual energy flows as a percentage of the total energy consumption of office buildings in percentages [%]. The following energy sources are valued as renewable according to BENG 3:

- Solar energy
- Geothermal energy
- Soil energy
- Thermal energy storage
- Wind energy
- Outside air energy
- Biomass
- Industrial waste heat

For office buildings in the Netherlands the largest energy consumers are lighting, heating and ventilation. For the local production of electrical energy though PV systems in office buildings the roof provides a relatively small surface due to the vertical orientation. Building integrated PV systems on the facades of office buildings can provide solutions for additional electricity production. Biomass fired boilers seem to be valued effectively within the NTA8800, providing options when the more sustainable solutions of reusing residual energy flows is not possible on the building location.

Conclusions financial feasibility
For the financial feasibility section, the following sub research question was presented:

What are the costs and benefits of energy efficient office buildings?

Literature was consulted on the cost and benefits of energy efficient and green office buildings. The findings are presented in the next sections.

Construction cost premiums
Construction cost premiums can be avoided when energy efficiency and sustainability are implemented during the early stages of the design process. Especially smart and bioclimatic design principles can be implemented without any additional construction costs when implemented in early design phases. The following minimal and maximal cost premiums were found in literature for offices with green building certificates (Rehm & Ade, 2013):

BREEAM:	0% – 3.3%
Australian Green Star:	0% – 6.2%
LEED:	1% – 9,6 %

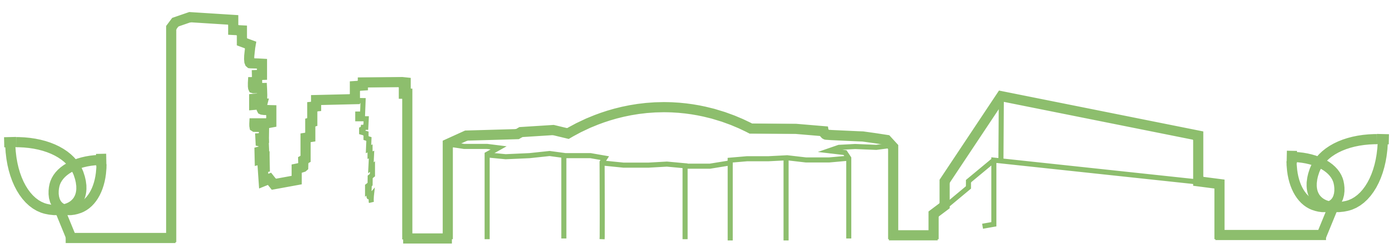
The BREAAM values for construction cost premiums will be presumed normative during the continuation of this research because BREAAM-NL is the green building certificate applied most in the Netherlands.

Added values
There can be identified multiple added values for energy efficient and green office buildings. Investors increasingly set high demands for their investments and they incorporate these Socially Responsible Investments into their investment strategies (PRI, 2018). Highly energy efficient office developments propositions are therefore more likely to receive equity from third parties. Companies increasingly attach importance to their corporate reputation through their sustainable offices. Developers of sustainable offices therefore have an advantage over their non-sustainable competitors. The operating costs for these users of energy efficient office buildings are lower, because cost for energy is responsible for 30% of the total operating costs of typical office buildings (Eichholtz, Kok, & Quigley, 2010). Furthermore, tenants of energy efficient office buildings are more likely to renew their rental contract and are more satisfied. Last but not least, the market value and gross rental income of office buildings are of great significance for developers. According to literature research there are the following minimal and maximal increased property values and rental prices for energy efficient office buildings in the Netherlands (ING, 2017; van Manen, 2019):

Higher market value:	8,6% - 9,10%
Higher gross rental income:	8,4% - 13,8%

When the findings from literature on the higher market values and gross rental income is compared with the construction costs premiums this already suggests that it is financially more profitable to develop energy efficient office buildings compared to non-energy efficient ones. Construction costs and market values, however, are not opposites in the balance sheet. The development costs (construction costs + development fee) and market values would provide a fairer picture. In general, developers strive for a minimal profit of 10% for their developments. This 10% however is always included in the market value, so it can be concluded that it is financially more profitable to develop energy efficient office buildings compared to non-energy efficient ones.

III. EMPERICAL RESEARCH



10. Case study protocol

In the following chapter the protocol for the obtaining of qualitative data through case studies and expert interviews is described. The protocol is deducted from the theory of the book: *Case Study Research Methods*, Yin (2014). In figure 9 the case study design is presented.

There are three case study protocol phases which can be identified in figure 7: the *define and design* phase, the *prepare, collect and analyse* phase and the *analyse and conclude* phase. Underneath the phases the individual steps of each phase are illustrated. These steps will be further elaborated in the following sections of this chapter. The three phases and the corresponding steps illustrated in figure 7 lead up to the products of the empirical research of this thesis.

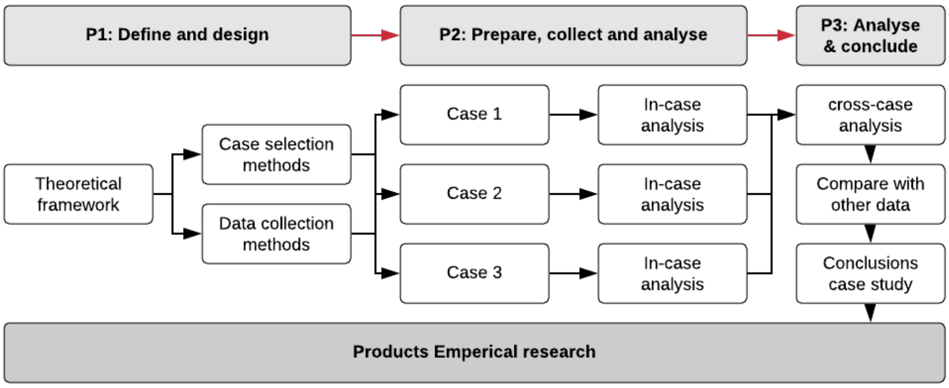


Figure 9: Case study design (Author (2020), adapted from Yin (2014))

10.1 Case selection method

Unit of analysis

The unit of analysis of the case studies performed in this chapter is the energy efficiency of office buildings which are considered zero energy according to the EPC and NEN7120. This thesis is written during a graduation internship at the real estate developer EDGE Technologies, making qualitative data available of zero energy developments of EDGE Technologies. The energy systems will be analysed on a technical and financial characteristic. Furthermore, the office buildings and their energy systems will be analysed on whether they meet the norms of BENG and the Paris Climate Agreement (Paris Proof). The unit of analysis is further described in the selection criteria section.

Selection criteria

For the purpose of this thesis three cases of office buildings which are considered zero energy according to the EPC and NEN7120 determination method are studied. Because this thesis is written as part of the internship at EDGE technologies, qualitative data was easily available to the researcher. Secondly, the cases that are studied need to be developments that have been completed recently or are still under construction during the conduction of the research for this thesis. This is due to the high degree of innovation in technology. Older projects do not implement the newest technologies, making them less insightful when it comes to the possibilities within BENG. Furthermore, the BENG norms are deemed most challenging for urban office developments, because they often don't have large surrounding plots to produce energy. Therefore, office buildings that are located in (central) business districts are selected for this case study. The last selection criterion is the design of the building itself. Because NTA 8800 and BENG 1 use the building compactness indicator as a measure to determine the total energy demand this compactness indicator should be different for the three cases, preferably two cases with extreme building compactness indicators and one case with a relatively moderate building compactness indicator. This is to provide insights into a broad spectrum of designs of office buildings and how they are affected by the BENG regulation and NTA8800 determination method. The compactness indicator of a building can be calculated by the following formula:

Building compactness indicator = A_{ls}/A_g *with:* A_{ls}= Envelope Surface [m2] *And* A_g = GFA [m2]

To summarise: the following selection criteria apply for this case study:
- Preferably a project developed by EDGE Technologies
- Project phase: recently completed (2018-2020) or currently under construction
- Energy performance: Zero Energy or Zero Carbon office building
- Location: business district of Amsterdam
- Cases should have a different building compactness indicator

Case study selection
From the selection criteria defined in the previous section the following cases are selected for this case study. As can be seen in in table 9 the cases that are selected on the basis of the selection criteria are EDGE Amsterdam West, EDGE Olympic and Valley. All three projects are developments of EDGE Technologies, currently under construction or recently finished and have a zero energy or zero carbon status. Al three are located in business districts in the city of Amsterdam. EDGE Olympic and Valley are located in the central business district of Amsterdam: the 'Zuidas'. The three building compactness indicators vary significantly, resulting in a broad spectrum of office building designs and how they are affected by the BENG regulation.

	EDGE Amsterdam West	**EDGE Olympic**	**Valley**
			
Developer	*EDGE Technologies*	*EDGE Technologies*	*EDGE Technologies*
Project type	*Redevelopment*	*Redevelopment*	*New build*
Project phase	*Under construction*	*Completed May 2018*	*Under construction*
Energy performance	*Zero energy building*	*Zero Carbon building*	*Zero Carbon building*
Location	*Business district Amsterdam* *Basisweg 10, Amsterdam*	*Central business district Amsterdam* *Fred. Roeskestraat 115, Amsterdam*	*Central business district Amsterdam* *Spoorslag, Amsterdam*
Building compactness indicator (B.C.I.)	A_{ls} = *Envelope surface = 38.136* m^2 A_g = *UFA= 51.066* m^2 *B.C.I. = 0.747*	A_{ls} = *Envelope surface = 11.207* m^2 A_g = *UFA= 11.716* m^2 *B.C.I. = 0.957*	A_{ls} = *Envelope surface = 45.939* m^2 A_g = *UFA= 44.538* m^2 *B.C.I. = 1.04*

Table 9: Case study selection (Author, 2020; derived from data from EDGE Technologies, 2019)

10.2 Data collection

The data that is collected for the cases will come from internal documents of EDGE Technologies and interviews with experts in the field of energy efficient office buildings. The data that is collected through the studying of these cases is checked and supplemented by the findings of the scientific framework. The data collection method is illustrated in figure 10. The data sources that will be used to collect data will be discussed in the following sections.

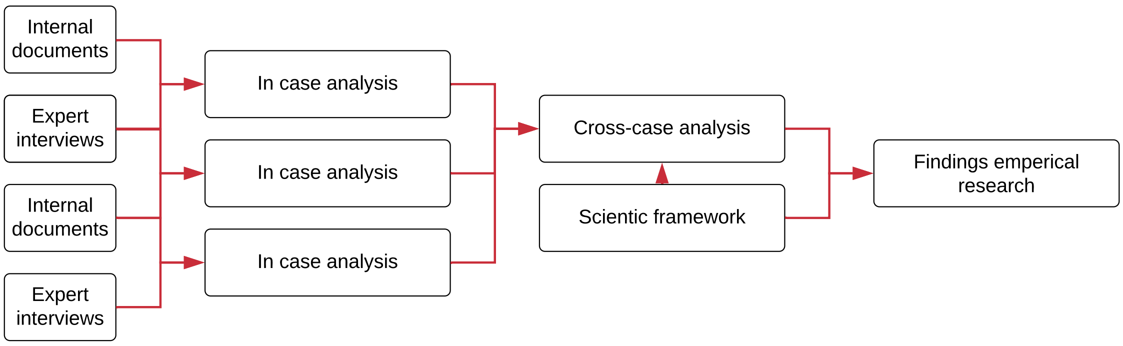


Figure 10: Data sources & flow for empirical research (author, 2020)

Internal documents EDGE Technologies

The internal documents of EDGE Technologies will provide insights on the energy performance of the cases studied and their finances. The data will be derived from two types of internal documents: EPC & energy consultation documents and contractor budgets and invoices. How these documents are used is explained in the next sections.

Technical internal documents

The data on the energy performance, building physics, floor areas and supply of renewable energy of the cases is derived from EPC calculations that are final or in a near final stage. During the research it quickly became apparent that different data sources and document types give quite different results when the data is used for further calculations. By always using the same source (EPC) for the same data types the reliability of the data increases significantly. When the required data is not available in the EPC calculation documents which are the preferred data sources, other internal documents of EDGE are consulted. These documents are provided by external advisors of EDGE Technologies, and these documents always need to be handled with caution and checked for reliability.

Financial internal documents

The data on the total construction cost and individual costs of energy efficiency measures are derived from feasibility studies, contracts, budgets and invoices provided by the contractors that are constructing or have constructed the cases studied. This data will provide insights on the development and construction costs of the building, financial structures and ownership structures.

Expert interviews

The semi-structured expert interviews that are conducted will be with experts on the energy efficiency of office buildings and experts on valuating the energy efficiency of office buildings. The interviews will have the following main purposes: providing qualitative data on energy policies, efficiency strategies and valuations, validating findings from literature, validating findings from EPC calculations and documents of external advisors. Furthermore, during these interviews, the NTA 8800, BENG and their implications on the development of office buildings will be discussed as well as the sources and their reliability and the overall line of reasoning of this thesis. The interview protocols that were used during the semi-structured interviews are provided in the appendices.

For the collection of extra qualitative data on the technical feasibility of BENG compliant and zero energy office buildings interviews will be conducted with experts on energy efficiency applications and regulations for office buildings. These experts are employees of consulting companies of Edge Technologies and other institutions engaging in energy efficient office buildings. The contacts for these interviews are facilitated by EDGE Technologies. For the full structure of the interviews see appendix A. The interviews are structured in the following way:

1. An introductory protocol
2. General introduction of the interviewee.
3. Questions about experiences with and knowledge of the BENG regulation and energy efficient office buildings.
4. Interviewees are asked whether they are open to participating in an expert panel to increase the reliability of the results of the research and technical design

Experts that are interviewed have the following roles within the field of energy efficient office buildings:

<u>Energy and Sustainable Building Consultants</u>
Multiple experts on providing energy efficiency counselling for office buildings and analysing the energy performance of office buildings which are used as case studies. Next to the conducted interviews, experts were consulted by phone or email during the conduction of the case studies when rarities where found in the available qualitative data from internal documents of EDGE Technologies.

One of the consultants that was interviewed was part of a team working on the BENG norms and calculation software for the NTA8800 determination method. With this interviewee a more in depth interview about the design and implications of BENG was conducted.

<u>Head of Certification and Project manager 'Delta plan Sustainable Renovation Netherlands'</u>
Expert on the Paris Climate Agreement and its implications for the Dutch building stock. Leads the research which resulted in the implications for individual buildings in order to meet the demand of the Paris Climate Agreement.

<u>PhD researcher on integrated Photovoltaic components for the built environment</u>
Expert on the development of renewable energy technologies with an emphasis on Building Integrated PV (BIPV) components. An explorative interview was conducted in order to provide an overview of the technical possibilities of BIPV and other renewable energy technologies.

<u>Director development transactions</u>
Expert on deal making and sale purchase agreements with investors of office buildings. Personal experiences on willingness to pay for energy efficiency aspects, corporate responsibility and monetary benefits of energy efficiency were discussed during the interview.

<u>Executive commercial development director</u>
Expert on deal making with tenants of office buildings. Personal experiences on willingness to pay for energy efficiency aspects, corporate responsibility and monetary benefits of energy efficiency were discussed during the interview.

Scientific literature
The findings from literature have two purposes during the empirical part of this research. Firstly, findings from the literature review are used to check the reliability of the findings of the case studies. When the case studies produce findings that seem unlikely and are incoherent with findings of the literature research, the experts are consulted and asked for their opinion in order to improve the reliability of the data input for the operational research part of this thesis.

The second purpose of findings from literature research is to supplement the findings of the case studies when the findings do not provide the required data for the design part of this research. The data that is lacking in the findings of the case studies can be of a specific energy system such as a biomass burner or building integrated PV, because this system was not applied in any of the cases.

10.3 Data analysis

The analysis that is collected by the methods described in the previous section is analysed in several ways which are described in this section.

In case-analysis
The in-case analysis of the projects of EDGE Technologies can be divided into four categories: the general attributes of the case, the technical aspects of the case, the financial aspects of the case and the labels and regulations which the case meets. Each category contains several aspects that will be analysed. The aspects and categories are schematically presented in figure 11.

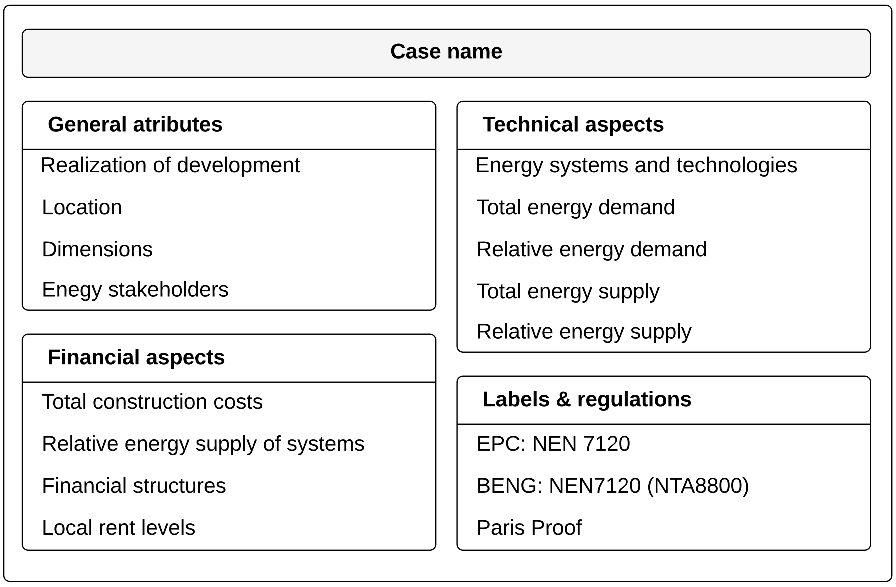


Figure 11: Structure of the in-case analysis (author, 2020)

All data for the in-case analysis of the cases is provided by internal documents of EDGE Technologies and explorative interviews with involved employees. The data for the general attributes is derived from explorative interviews, EPC calculations, feasibility studies, contracts and contractor budgets. The data for technical aspects of the in-case analysis is derived from EPC calculations of the buildings. The data for the financial aspects of the in-case analysis is derived feasibility studies, contracts, budgets and invoices provided by the contractors of the cases. The labels and regulation category will compare the findings of the previous three categories with the findings from literature review and expert interviews.

Cross-case analysis
The findings of an in-case analysis will be compared with the other cases for a cross-case analysis. The findings are also compared with findings from literature, in order to increase the reliability of the findings from the cross-case analysis. The structure of the cross-case analysis is illustrated in table 10.

	EDGE West	**EDGE Olympic**	**Valley**
General attributes			
Location			
Dimensions			
Energy stakeholders			
Technical aspects			
Total energy demand			
Relative energy demand			
Total energy supply			
Relative energy supply			
Energy systems			
Financial aspects			
Total construction costs			
Relative construction costs			
Financial structures			
Local rent levels			
Labels & regulations			
EPC: NEN 7120			
BENG: NEN7120 (NTA 8800)			
Paris proof			

Table 10: Structure of the in-case analysis (author, 2020)

10.4 Products
The findings of the cross-case analysis are compared with the findings of the literature study. The result of this are the products of the empirical research of this thesis. The products of the empirical research of this thesis are:

- Insights in three zero energy office buildings in Amsterdam, the Netherlands
- List of energy producing measures for office buildings quantified on cost and energy production.
- List of energy saving measures for office buildings quantified on cost and energy savings
- Financial and/or operational structure behind energy systems of cases

11. EDGE Amsterdam West

11.1 The development

EDGE Amsterdam West is a redevelopment of EDGE Technologies of what was originally one of the first office buildings in what is now the Sloterdijk business district. The project is located on Basisweg 10. The construction year of the original building was 1970 and it was designed by former architect Arnold Numan Oyevaar. During the financial crisis of 2008 EDGE Technologies acquired the building, and in 2019 started the redevelopment after selling the property to a consortium of Korean investor Hana Alternative Asset Management and NH investments.

During the redeployment of EDGE Amsterdam West, the top floor of the building which was originally used for installations was transformed to an office floor by moving the installations to the basement and thereby adding approximately 6.700 m^2 of Lettable Floor Area to the property. Besides adding these square meters to the development, the unused outside area in the centre of the property will be covered by a large atrium creating a central meeting space with a restaurant and coffee corners. The main tenants of the multi-tenant office building will be the companies APG and Alliander and the planned completion date of the main building is spring 2021 and of the outbuilding mid 2020.

EDGE Technologies together with the main tenants have the ambition to realize a *building-related energy-positive on-site energy balance* for EDGE Amsterdam West. This ambition results in the building-related installations annually generating more energy than they consume. Furthermore, the building will be ‘smart’ following the EDGE Blueprint which will enable tenants to control lighting, heating, lockers, screens and other technical applications through an app on their smart phone. Sensors in EDGE Amsterdam West will track the energy performance of the building which will be displayed on dashboards.

Figure 12: Birdseye view render of the development of EDGE Technologies: EDGE Amsterdam West (EDGE, n.d.-a)

General attributes

For determining the energy efficiency of a building according to the NEN 7120 determination method the Usable Floor Area (UFA) (*Dutch: Gebruiks Oppervlak (GO))* is used. Next to this the total envelope surface of a building is necessary for determining the energy efficiency. For the BENG regulation these areas are needed for determining the building compactness indicator. The UFA of EDGE West is 51066,4 m^2, with a total envelope surface of 38148,9 m^2. This makes the Building Compactness Indicator (B.C.I.) 0.747.

Energy stakeholders

The main contractor of EDGE Amsterdam West is *G&S Bouw*. For the total construction of the building many subcontractors are involved, but the sub-contractor that is responsible for all the installations is *Bosman Bedrijven*. For the PV installation *Devcon* is the responsible sub-contractor, constructing all the PV-systems on the terrain. The main energy consultant at the EDGE Amsterdam West is DWA, with Leon Burdorf being the responsible engineer within the DWA organisation for EDGE Amsterdam West. Lastly, Eneco is involved as an energy stakeholder for EDGE Amsterdam West. Eneco is an energy company that will buy the thermal energy storage system and sell the produced heat to the tenants of the building.

EDGE Amsterdam West	Areas
GFA	65.000 m²
LFA	48.000 m²
UFA / A_g	51.066 m²
Envelope surface / A_{ls}	38.136 m²

EDGE Amsterdam West	Stakeholder
Main contractor	G&S Bouw
Energy installations sub-contractor	Bosman Bedrijven
Energy advisor	DWA (Leon Burdorf)
Energy operator (WKO & PV)	Eneco

Table 11 & 12: Floor areas and energy stakeholders EDGE Amsterdam West

11.2 Technical aspects

Energy demand

Calculated according to NEN7120 the total uncorrected energy demand of EDGE Amsterdam West is 2.656.658 kWh per year, which translates to 52,02 kWh/m² per year. How the energy consumption is distributed within the building can be seen in table 13.

Building-related energy consumption		
	[kWh/year]	[kWh/m²/year]
Heating	728.372	14,26
Water	270.258	5,29
Cooling	225.914	4,42
Ventilation	453.304	8,88
Lighting	978.811	19,17
Total	2.656.659	52,02

Table 13: Energy demand EDGE Amsterdam West

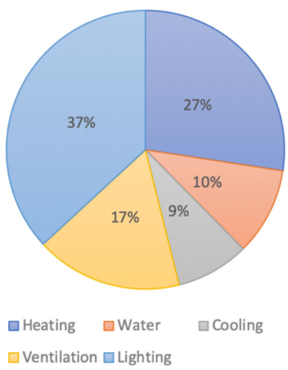


Figure 13: Relative energy demand EDGE Amsterdam West

Some technical applications of EDGE Amsterdam West meant to reduce the total energy demand of the building are the following:

Heating & cooling

- Adding extra insulation on the roof, basement and facades.
- Use of high-quality glazing with thermally interrupted frames.

Ventilation

- Demand-driven ventilation based on presence.
- Application of energy-efficient fans and pumps in the climate system.

Lighting

- Optimally coordinated glass configuration in relation to sun protection and light entry.
- LED lighting with daylight control and switching based on presence.

Energy supply
The remaining energy demand is fully generated from renewable sources on site. EDGE Amsterdam West's energy producing system consists of a photovoltaic installation (PV) for electricity generation and a thermal energy storage system on site supplemented with reversible air-to-water heat pumps for heat and cold generation. The PV is placed on the roof of the main building and outbuilding, on top of the parking, in the backyard and a small showcase in the front yard. In total there is 5.555 m^2 of PV needed to compensate the remaining demand of EDGE Amsterdam West. In addition, the building is equipped with an all-electric installation concept. For more information on the specifications of the PV installation of EDGE Amsterdam West see table 14. For the supply of sustainable heat and cold to the building, Edge Technologies intends to commission Eneco for the realization and operation of a sustainable energy generation installation consisting of a thermal energy storage system (WKO) with heat pumps, an electric boiler and air-to-water heat pumps. The heat output of this system is 2,056 kW and the cold output is 2,880 kW.

Building-related energy supply		
	[kWh/year]	[kWh/m2/year]
PV on building roof	649.997	12,73
PV on site	1.052.376	20,61
Thermal energy storage	954.286	18,69
Total	2.656.883	52,03

Table 14: Energy supply EDGE Amsterdam West

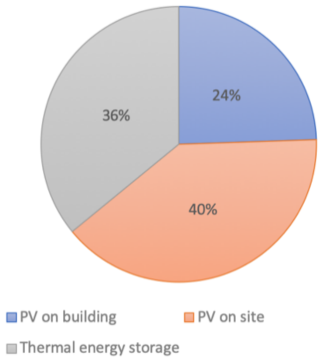


Figure 14: Relative energy supply EDGE Amsterdam West

As can be seen in Table 13 and figure 13 the relatively largest energy consumers within EDGE Amsterdam West are lighting, heating and ventilation. The (relative) supply of energy can be seen in table 14 and figure 14. Firstly, it becomes apparent that the calculated total energy supply is larger than the total energy demand per m^2: 52.03 kWh vs 52.02 kWh.

Secondly, because EDGE Amsterdam West will use a thermal energy storage system (WKO) with heat pumps, an electric boiler and air-to-water heat pumps, the energy needed for heating and cooling the building is almost completely supplied sustainably, leaving lighting and ventilation as the largest energy consumers.

Lastly, of the total energy supply 24% is generated with PV-panels that are located on the building, 36% is generated by the thermal energy storage system and 40% is generated on site, but not on the building itself. This is quite a unique situation for a building in a business district to have a surrounding plot where there is space for placing additional PV panels.

11.3 Financial aspects

Costs

The total construction cost of EDGE Amsterdam West and the costs for the energy measures are illustrated in table 15. The energy systems that are considered for this case study are the thermal energy storage system and the total PV installation. The relative costs of the energy measures compared to the total construction costs and the relative cost difference between systems is illustrated in figure 15.

Building costs	
Total construction costs	€ 82.400.282, -
Sustainable energy supply	**Construction costs**
Thermal energy storage system	€ 1.688.138,03
PV installation 5500 m²	€ 1.161.557,51
Total cost energy measures	**€ 2.849.695,54**

Table 15: Construction costs EDGE Amsterdam West

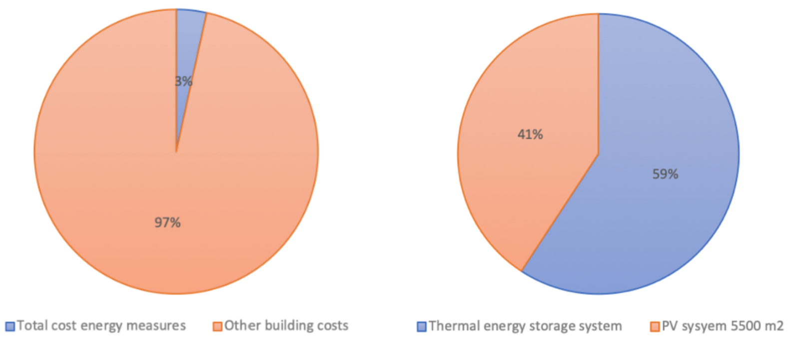


Figure 15: Relative costs of the energy producing measures for EDGE Amsterdam West

As can be seen in figure 15 the relative costs of the energy producing measures of EDGE Amsterdam West are 3% compared to the total construction costs. The construction costs of the thermal energy storage system are slightly larger than the costs for the PV system.

Benefits/ opportunities

The financial and operational structure behind the energy producing systems of EDGE Amsterdam west is as follows: EDGE technologies will develop and build the PV system and the thermal energy storage system in association with the contractors of EDGE Amsterdam West. When the development is delivered the energy producing systems are sold to Eneco. The investment costs for EDGE are shown in table 16.

Energy measures	Construction costs	[kWh year 1]	[€ /kWh (year 1)]
Thermal energy storage system	€ 1.688.138,03	954.286	€ 1,77
PV system 5500 m²	€ 1.161.557,51	1.702.373	€ 0,68

Table 16: Construction costs of sustainable energy supply EDGE West

However, on the project balance these systems are almost cost-neutral for EDGE Technologies. This means that there is no direct profit or loss over the development costs of the energy producing systems. Eneco will operate and maintain the energy systems and will therefore receive reimbursement of the tenants of EDGE Amsterdam West. The price the tenants will have to pay for their electricity is contractually established according to the *'niet meer dan anders'* (no more than usual) principle. This is a principle in the Netherlands where suppliers of energy cannot ask more for their (renewable) energy than then when this energy would be generated non-renewably. The average price of electricity in the Netherlands for non-household consumption classes who consume more than 150.000 kWh per year is €0,075 (CBS, 2020). The payback periods of the two energy producing systems operated by Eneco are shown in table 17.

System	Energy production per year [kWh]	Income per year (Eneco) [€]	Construction costs [€]	Payback period [Year]
PV	1702373.0	€ 127,677.98	€ 1,161,557.51	9.1
Thermal energy storage	954286.0	€ 71,571.45	€ 1,688,138.03	23.6

Table 17: Payback period energy producing systems EDGE Amsterdam West

Table 17 shows that the PV system at EDGE Amsterdam West provides a better business case for Eneco than the thermal energy storage system : the payback period of the PV system is less than half of the thermal energy storage system. For the determination of the payback period no indexation was used, and no maintenance costs are considered, but it illustrates the difference in financial feasibility of the systems.

The average rent level at EDGE Amsterdam West is €250, - per m^2 per year. This rent level is lower than rent levels that can be obtained in the central business district of Amsterdam, but according to van Manen (2019) €250, - per m^2 per year is still higher that the Amsterdam and national average for label A office buildings.

11.4 Labels & regulations

EPC: NEN 7120

When the environmental permit was issued for EDGE Amsterdam West the building still fell under the current energy efficiency regulation and determination method EPC and NEN 7120. According to the NEN 7120 EDGE Amsterdam west is energy positive on site for the building-related energy consumption is 224 kWh/m2/year less than the production, resulting in a specific energy performance of 0 per m^2.

BENG: NEN 7120 (NTA 8800)

Because the NTA 8800 have not been published at the moment this thesis is written, the old determination method is used for checking EDGE Amsterdam West's compatibility with the BENG norms. In table 18 the norms and the scores of EDGE Amsterdam West are presented.

	BENG 1 Energy requirement [kWh/m².yr]	BENG 2 Primary fossil energy consumption [kWh/m².yr]	BENG 3 share renewable energy [%]
2015 - NEN 7120	≤ 50	≤ 25	≥50
	33,6	**0,0**	**100**
2019 - NTA 8800	*Als/Ag* ≤ 1,8 BENG 1 ≤ 90 *Als/Ag*> 1,8 BENG 1 ≤ 90 + 30 * (Als/Ag -1,8)	≤ 40	≥30
EDGE Amsterdam West	**33,6**	**0,0**	**100**

Table 18: BENG compatibility of EDGE Amsterdam West with the BENG norms

As can be seen in table 18 EDGE Amsterdam West complies with both the old BENG norms with the NEN 7120 method and the new BENG norms. The new norms are still calculated with the old determination method. EDGE Amsterdam West is a zero-energy on-site office building for the building-related energy consumption.

Paris Proof
EDGE Amsterdam West has a building-related energy demand of 0. This is because the building related energy demand is fully compensated by renewable energy production on site. An office building is Paris Proof when the building-related energy consumption is less than 35 kWh/m^2/year. This makes EDGE Amsterdam West a Paris Proof building.

11.5 Conclusion & discussion

EDGE Amsterdam West is a zero-energy on-site office building which complies with the new BENG regulations. It can be seen as an example on how to develop zero energy on site office buildings within the energy regulations in the Netherlands. This being said, 40% of the renewable energy is generated on the surrounding plot of the building. Without such a large surrounding plot EDGE Amsterdam West wouldn't be able to reach this zero-energy status with the current design.

The financial and ownership structure of the energy producing systems of EDGE Amsterdam West makes them relatively risk and equity free from the developer's perspective, and for Eneco it seems like a feasible business case to operate and maintain the systems. With this structure however, tenants of the office building do not experience the benefits of it being zero-energy: they pay their electricity bills like they would have done when they were using grid-provided electricity. EDGE Technologies probably did receive a premium for the sale of its building because it is zero-energy, making the end users of the building the only stakeholders that are not feeling the financial benefit of the zero-energy building

EDGE West is BENG compliant, and zero-energy, due to its surrounding plot. Should the energy generated on this plot not be considered BENG 2 would become 31.2 and BENG 3 60%, which is still BENG compliant.

12. EDGE Olympic

12.1 The development

EDGE Olympic is a redevelopment of EDGE Technologies of an excising office building on the border of the central business district of Amsterdam 'Zuid-as", located on the Frederik Roeskestraat 115. The construction year of the original building was during the 1990s. The redevelopment was initiated when the property was sold to TH Real estate which was Nuveen real estate during the time of the sale purchase agreement. During the redevelopment of EDGE Olympic approximately 5.400 m² was added on top of the original building resulting in a building of 12,434 m² GFA, thereby increasing the lettable floor area significantly.

EDGE Amsterdam West was sold and leased back by EDGE Technologies. EDGE Technologies partners with Epicentre, in which it holds 30% of the shares, and lets the building under a multi-tenant concept. The first three main tenants of EDGE Olympic were Ebbinge, EVBox en Software Improvement Group (SIG). EDGE Olympic was completed in 2018 and is now the head office of EDGE Technologies.

Figure 16: Render of the development of EDGE Technologies: 'EDGE Olympic' (Cie, 2018)

General attributes

EDGE Olympic is a multi-tenant office building located in the Frederik Roeskestraat on the border of the commercial district in Amsterdam. EDGE Technologies redeveloped the original office building of approximately 7,000 m² GFA and after redevelopment the building consists of 12,434 m² GFA. The building was officially delivered by EDGE Technologies in May 2018 and is now the head office of the developer. The UFA of EDGE Olympic is 11.517 m², with a total envelope surface of 10.649 m². This makes the building compactness indicator (B.C.I.) 0,957.

Energy stakeholders

The main contractor of EDGE Olympic was JP van Eesteren. For the total construction of the building many subcontractors are involved, but the main energy sub-contractor is Bosman Bedrijven. Bosman Bedrijven is the sub-contractor responsible for all the installations. The main energy consultant at the EDGE Olympic is DGMR, with Mirjam Peters being the responsible engineer within the DGMR organisation for EDGE Olympic. Lastly, Eneco is involved as an energy stakeholder at EDGE Olympic. Eneco as an energy company will provide the connection with the heat network.

EDGE Olympic	Areas
GFA	12.434 m²
LFA	10.000 m²
UFA / A_g	11.517 m²
Envelope surface / A_{ls}	10.649 m²

EDGE Olympic	Stakeholder
Main contractor	G&S Bouw
Energy installations sub-contractor	Bosman Bedrijven
Energy advisor	DGMR (Mirjam Peters)
Supply of renewable energy	VVE's, Sunrock, Eneco

Table 19 & 20: Floor areas and energy stakeholders EDGE Olympic

12.2 Technical aspects

Energy demand

Calculated with the NEN 7120 the total uncorrected building-related energy demand of EDGE Olympic is 748.872 kWh per year, which translates to 65.02 kWh per m² per year. How the energy consumption is distributed within the building can be seen table 21 and figure 17. The data for the table is from EPC calculations of DGMR (2017a).

Building-related energy consumption		
	[kWh/year]	[kWh/m²/year]
Heating	204.226	17,73
Water	80.384	6,98
Cooling	79.815	6,93
Ventilation	123.145	10,69
Lighting	320.725	27,85
Total	808.295	70,18

Table 21: Energy demand EDGE Olympic

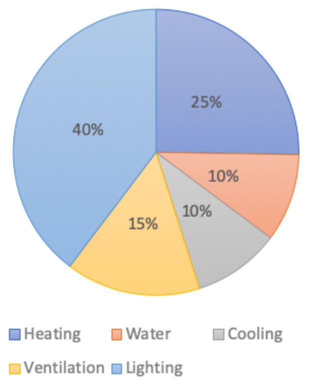


Figure 17: Relative energy demand EDGE Olympic

Some technical applications of EDGE Olympic with the purpose of reducing the total energy demand of the building are the following:

Heating & cooling

- Smart integrated systems, only heating and cooling when necessary
- User preference systems for heating & cooling

Ventilation

- Solar chimney (Atrium) for natural ventilation outlet
- Application of energy-efficient fans and pumps in the climate system.

Lighting

- LED lighting with daylight control and switching based on presence.
- User preference systems for heating & lighting

Energy supply
The supply of renewable energy for EDGE Olympic comes from energy sources off- and on-site. EDGE Olympic's on-site energy producing system consists of a PV-system that is located on the roof of the building. This PV system generates 335.069 kWh per year. EDGE Olympic is connected to a heat network which supplies the building of sustainable heat, which translates to 204.226 kWh per year. Lastly, EDGE Olympic allocates energy that is generated off-site through PV panels to its energy balance. This alloction of renewable energy that is generated off-site for EDGE Olympic will be formatized according to the NEN 7125: Energy measures at area level (RV,n.d.,g). The energy that is generated at external locations will not be used directly for supplying EDGE Olympic, but it will be allocated to the energy performance of EDGE Olympic under the condition that the generated energy will not be used at any other location for energy performance regulations or sustainability certificates. This is to prevent double counting of renewable energy. The energy that is allocated for the energy performance of EDGE Olympic comes from two housing projects and one large project provided by Sunrock.

EDGE Olympic will allocate energy from an external location within a 10 km radius of the project. The external PV will allocate 269.000 kWh per year to the EPC of EDGE Olympic.

Building-related energy supply		
	[kWh/year]	[kWh/m2/year]
PV on-site	13.387	1,16
PV off-site	592.672	51,46
Heat network	204.226	17,73
Total	808.295	70,36

Table 22: Energy supply EDGE Olympic

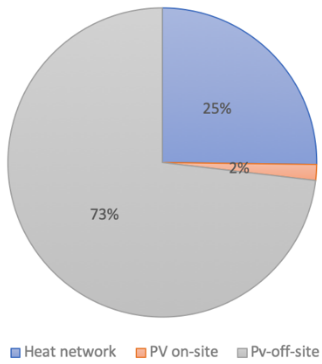


Figure 18: Relative energy supply EDGE Olympic

As can be seen in Table 21 and figure 17 the relatively largest energy consumers within EDGE Olympic are lighting and heating, followed by ventilation. The (relative) supply of energy can be seen in table 22 and figure 18. The supply of renewable energy comes for 73% from external PV which is allocated to the EPC of the building, 25% from the heat network and 2% from PV that is located on the roof of the building. The total energy demand of EDGE Olympic is met by the renewable energy supply.

Because EDGE Olympic is connected to the heat network the energy needed for heating the building is completely supplied sustainably, leaving lighting and ventilation as the largest energy and electricity consumers.

Lastly, to meet the total energy demand of the building 25% of the energy is supplied from district heating, 73% is generated with PV-panels that are located outside of the building plot, and 2% is generated on with PV on-site. Without the allocation of energy that is generated outside the building plot EDGE Olympic would not have been able to realize a building-related energy positive energy balance.

12.3 Financial aspects

Costs

The total construction cost of EDGE Olympic and the costs for the energy measures are illustrated in table 23. The energy systems that are considered for this case study are the heat network and the total PV installations. The relative costs of the energy measures compared to the total construction costs and the relative cost difference between systems is illustrated in figure 19.

Building costs	
Total construction costs	€ 16.339.000, -
Sustainable energy supply	**Construction costs**
Heat network	€ 50.589, -
External PV	€ 43.000, -
Internal PV roof	€ 25.000, -
Total cost energy measures	€ 118.589, -

Table 23: Construction costs EDGE Olympic

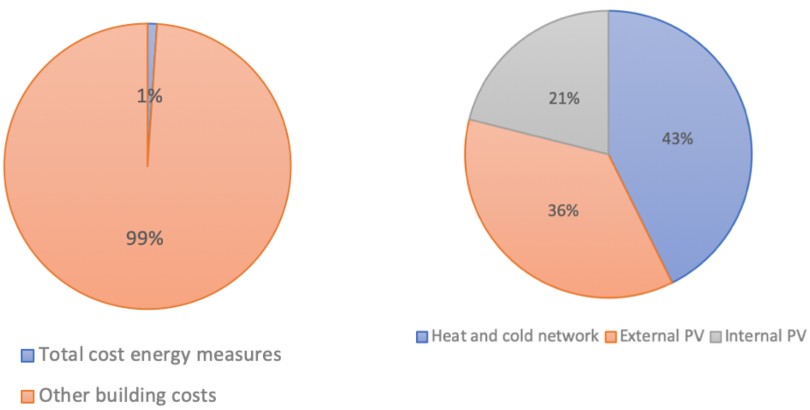


Figure 19: Relative costs of the energy producing measures for EDGE Olympic

As can be seen in figure 19 the relative costs of the energy producing measures of EDGE Amsterdam West are (less than) 1% compared to the total construction costs. The construction costs of the thermal energy storage system are slightly higher than the costs for the PV system. The costs for the PV that is located on the roof of the building are relatively the lowest, whereas this is the largest energy producer of EDGE Olympic.

Benefits/ opportunities

In table 24 the construction costs per kWh for the heat network and allocation of external PV of EDGE Olympic are presented. What immediately becomes evident is that using external PV and allocating the generated energy to the EPC is the most cost efficient for a developer to improve the energy performance of the building.

Energy measures	**Construction costs**	**[kWh year 1]**	**[€ /kWh]**
Heat network	€ 50.589, -	204.226	€ 0,25
PV off-site	€ 43.000, -	592.672	€ 0,07
PV on-site	€ 25.000, -	13.387	€ 1,87

Table 24: Costs of sustainable energy supply EDGE Olympic

The financial structure behind the allocation of sustainable energy through external PV is that EDGE Technologies approaches a third party who already has the ambition to realise PV for the supply of renewable energy and thereby reducing the energy costs on their own location. EDGE Technologies makes a contribution to the business case of this party in exchange for the right to use the generated energy to improve the energy performance of EDGE Olympic. The contribution of EDGE Technologies represents approximately 12% of the required investment by Bosman Van Zaal and Sunrock for the PV to be realized for Valley, making the investments for Bosman Van Zaal and Sunrock economically profitable.

The average rent level when EDGE Olympic was rented out (2018) was €300 - €325 per m^2 per year. Currently (2020) the average rent level at Edge Olympic is €400 - €450 per m^2 per year. This shows the tightness of the current market. Both the delivery rent level and the current rent level are higher that the Amsterdam and national average for label A office buildings according to van Manen (2019).

12.4 Labels & regulations

EPC: NEN 712

When the environmental permit was issued for EDGE Olympic the building still fell under the current energy efficiency regulation and determination method EPC and NEN 7120. According to the NEN 7120 EDGE Olympic is a zero-energy building for the building-related energy consumption, resulting in a specific energy performance with an EPC of 0.

Besides this, the office building has an energy label A, has achieved a 79.11% in the assessment of BREEAM-NL, has one of the highest circularity scores on the Madaster platform and is the first building in the Netherlands to obtain the WELL: Core & Shell Certification.

BENG: NEN 7120 (NTA 8800)

Because the NTA 8800 has not been published at the moment this thesis is written, the old determination method is used for checking EDGE Olympics compatibility with the BENG norms. In table 25 the norms and the scores of EDGE Olympic are presented.

	BENG 1 **Energy requirement** **[kWh/m².yr]**	**BENG 2** **Primary fossil energy consumption [kWh/m².yr]**	**BENG 3** **share renewable energy** **[%]**
2015 - NEN 7120	≤ 50	≤ 25	≥50
EDGE Amsterdam West	***39,6***	**44,36**	**26,7**
2019 - NTA 8800	*Als/Ag* ≤ 1,8 BENG 1 ≤ 90 *Als/Ag*> 1,8 BENG 1 ≤ 90 + 30 * (Als/Ag -1,8)	≤ 40	≥30
EDGE Amsterdam West	***39,6***	**44,36**	**26,7**

Table 25: BENG compatibility of EDGE Olympic with the BENG norms

As can be seen in table 25 EDGE Olympic does not comply under the old BENG norms of 2015 with the NEN 7120 method and does not comply under the 2019 BENG norms. The new norms are still calculated with the old determination method. EDGE Olympic would not be considered a zero-energy office building for the building-related energy consumption according the BENG regulation.

Paris Proof

EDGE Olympic has a building-related energy demand of 44,36 kWh/m²/year when the allocation of external PV to the energy balance of the building is not considered. An office building is Paris Proof when the building-related energy consumption is less than 35 kWh/m²/year. 44,36 kWh/m²/year is significantly above 35 kWh/m²/year for an office building to be Paris Proof and therefore EDGE Olympic is not Paris Proof.

12.5 Conclusions & discussion EDGE Olympic

EDGE Olympic is an office building which is considered a zero-energy-office building under the current NEN 7120 EPC regulations but would EDGE Olympic have been developed under the BENG NTA8800 regulation it would not have been considered zero-energy. 57% of the energy that is considered renewable energy under the NEN 7125: Energy measures at area level is not effective under the BENG regulation. This allocation of energy that is generated off-site is, from the developer's perspective, a highly cost-efficient solution within the EPC regulation to achieve a better energy performance in the EPC. Compared to the costs for the heating and cooling network only 36% of the total costs is needed for the external PV, whereas 73% of the renewable energy in the EPC is derived from energy generation from external PV.

13. Valley

Figure 20: Render of the development of EDGE Technologies: 'Valley' (MVRDV, 2018)

13.1 The development

Valley is a mix use development located in the Beethovenstraat in the commercial district of Amsterdam. The building is currently being developed and will have a GFA of approximately 75.000 m^2 and an LFA of 46.200 m^2. The building consists of approximately 20.000 m^2 LFA residential, 22.000 m^2 LFA office, 2.700 m^2 LFA restaurant and retail, 1.200 m^2 LFA culture functions and 375 parking spaces. EDGE Technologies is currently developing the building and has the ambition to realize a building-related energy positive energy balance for Valley (EDGE, 2019). The UFA of Valley is 44.538 m^2, with a total envelope surface of 45.940 m^2. This makes the building compactness indicator (B.C.I.) 1,031.

Energy stakeholders

The main contractor of EDGE Amsterdam West is G&S Bouw. For the total construction of the building many subcontractors are involved, but the installations sub-contractor is Bosman Bedrijven. Bosman Bedrijven is the sub-contractor responsible for all the installations. The main energy consultant at Valley is DGMR, with Erik Cremers being the responsible engineer within the DGMR organisation for Valley. Lastly, Valley uses external locations to generate enough energy to realize a building-related energy positive energy balance.

Valley	Areas
GFA	75.000 m^2
LFA	46.200 m^2
UFA / A_g	51.066 m^2
Envelope surface / A_{ls}	44.538 m^2

Valley	Stakeholder
Main contractor	G&S Bouw
Energy installations sub-contractor	Bosman Bedrijven
Energy advisor	DGMR (Erik Cremers / Erik Boe)
External renewable energy suppliers	Nuon, Bosman van Zaal, Sunrock

Table 26 & 27: Floor areas and energy stakeholders EDGE Amsterdam West

13.2 Technical aspects

Energy demand
Calculated with the NEN 7120 the total uncorrected building-related energy demand of Valley is 2.960.567 kWh per year, which translates to 66,57 kWh per m² per year. How the energy consumption is distributed within the building can be seen in figure 21. The data for table for is collected from EPC calculations of DGMR (2017b).

Building-related energy consumption		
	[kWh/year]	[kWh/m²/year]
Heating	830.011	18,64
Water	438.168	9,84
Cooling	288.080	6,47
Ventilation	430.033	9,66
Lighting	974.274	21,88
Total	2.960.567	66,47

Table 28: Energy demand Valley

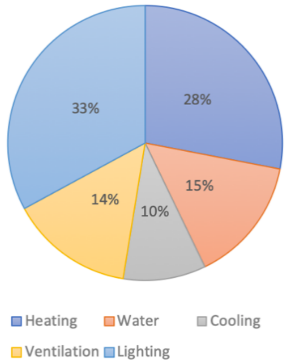


Figure 21: Relative energy demand Valley

Energy supply
The building-related energy demand of Valley is generated from renewable energy sources that are almost entirely off-site. Valley's energy producing system consists of a on- and off-site photovoltaic installation (PV) for electricity generation and district heating for the generation of heat and cold. To achieve an energy positive status the building needs to produce more energy than it yearly consumes. The residual heat of NUON's power plant in Diemen is used for the supply of heat and the 'Nieuwe Meer', a lake in the district of Amsterdam, is used for district cooling. The district heating and cooling provide most of the heating and cooling demand of the building but the ambition of Valley remains being an Energy Positive Building. To obtain this status a large share of the renewable energy is generated outside of the plot. In the case of Valley, the energy efficiency is measured with the current Dutch standard for energy efficiency of buildings: EPC. To make Valley energy positive, measured according to the EPC, an additional 2.050.000 kWh of electrical energy must be generated sustainably in order to achieve an EPC of -0,3. The rest of the renewable energy that needs to be generated is generated by PV. These PV-panels will almost all be placed off-site, due to the relative scarcity of roof surface. The amount of PV panels that can be placed on the roof of the building will be determined by the area that is available after other installations with a higher priority have been placed, such as the rails needed for cleaning and maintenance of the façade. Therefore, the PV that is placed on-site is neglected in this study.

The alloction of renewable energy that is generated off-site for Valley will be formatized according to the NEN 7125: Energy measures at area level (RV,n.d.,g). The energy that is generated at the external locations will not be used directly for supplying Valley, but it will be allocated to the energy performance of Valley under the condition that the generated energy will not be used at any other location for energy performance regulations or sustainability certificates. Valley will allocate energy from two external locations within a 10 km radius of the project: Bosman van Zaal and Sunrock. Bosman van Zaal is a producer of greenhouses and Sunrock a supplier of solar energy. Bosman van Zaal will develop the PV-panels on its own initiative and will allocate 702.475 kWh/year to the EPC of Valley. Sunrock will also develop the PV-panels on its own initiative and will allocate 1.347.525 kWh/year to the EPC of Valley.

Because Valley is currently being developed, energy efficiency strategies and specifications that are stated here are not yet final and can change over time.

Building-related energy supply		
	[kWh/year]	[kWh/m2/year]
PV on-site	-	-
PV off-site Bosman	702.475	15,77
PV off-site Sunrock	1.347.525	30,26
Heat & cold network	1.118.091	25.10
Total	3.331.672	74,81

Table 29: Energy supply Valley

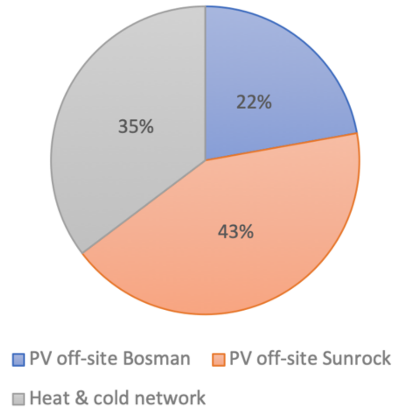


Figure 22: Relative energy supply Valley

As can be seen in Table 28 and figure 21 the relatively largest energy consumers within Valley are lighting and heating. Warm water and ventilation are also large consumers. The (relative) supply of energy can be seen in table 29 and figure 22. Firstly, it becomes apparent that the calculated total energy supply is significantly larger than the total energy demand per m^2: 74,91 kWh vs 66,47 kWh. This being said, it should be noted that the energy 'supply' is more than 2/3 from external locations.

Secondly, because Valley is connected to the heat and cold network, the energy needed for heating and cooling the building is almost completely supplied sustainably, leaving lighting and ventilation as the largest energy and electricity consumers.

Lastly, to meet the total energy demand of the building 38% of the energy is supplied from district heating and cooling, 62% is generated with PV-panels that are located outside of the building plot, and 0-1% is generated with PV on-site. Without the allocation of energy that is generated outside the building plot Valley would not have been able to realize a building-related energy positive energy balance.

13.3 Financial aspects

Costs

The total construction cost of Valley and the costs for the supply of sustainable energy are illustrated in table 30. The systems that are considered for this case study are the thermal energy storage system and the total PV installation. The relative costs of the energy measures compared to the total construction costs and the relative cost difference between systems is illustrated in figure 23.

Building costs	
Total construction costs	€ 130.080.000, -
Sustainable energy supply	**Construction costs**
Heat network	€ 1.889.351, -
External PV Sunrock	€ 235.750, -
External PV Bosman v Zaal	€ 100.000, -
Total cost energy measures	€ 2.225.101, -

Table 30: Construction costs Valley

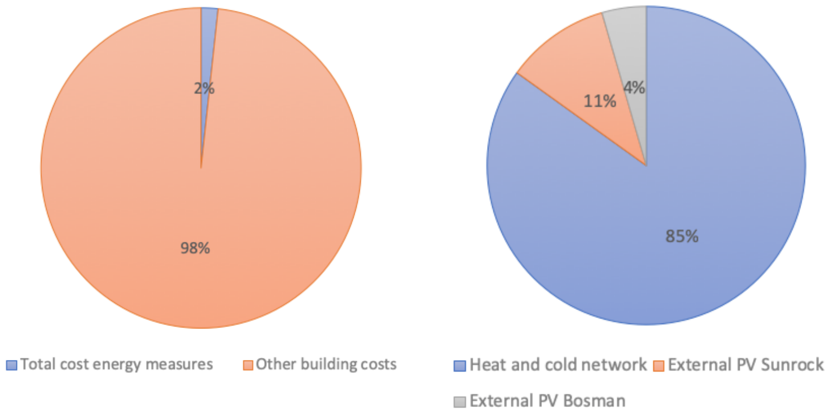


Figure 23: Relative costs of the energy producing measures for Valley

As can be seen in figure 23 the relative costs for the supply of renewable energy for Valley is 2% compared to the total construction costs. The majority of the costs is formed by the connection costs of the heat and cold network, only 15% of the costs for the supply of renewable energy are derived from the allocation of energy through external PV.

Benefits/ opportunities
In table 31 the costs per kWh for the heat and cold network and allocation of external PV are presented. What immediately becomes evident is that using external PV and allocating the generated energy is the most cost efficient for a developer to improve the energy performance of the building.

Energy measures	Costs	[kWh]	[€ /kWh]
Heat and cold network	€ 1.889.351, -	1118091	€ 1,69
External PV Sunrock	€ 235.750, -	1347525	€ 0,17
External PV Bosman	€ 100.000, -	702475	€ 0,14
Total external PV	€ 335.750, -	2050000	€ 0,16

Table 31: Costs of sustainable energy supply Valley

The financial structure behind the allocation of sustainable energy through external PV is that EDGE Technologies approaches a third party who already has the ambition to realise PV for the supply of renewable energy and thereby reducing the energy costs on their own location. EDGE Technologies makes a contribution to the business case of this party in exchange for the right to use the generated energy to improve the energy performance of Valley. The contribution of EDGE Technologies represents approximately 12% of the required investment by Bosman Van Zaal and Sunrock for the PV to be realized for Valley, making the investments for Bosman Van Zaal and Sunrock economically profitable. For the energy supplied from the heat and cold network EDGE Technologies pays a fixed sum of €1.889.351, - for the connection to the heat and cold network. The average rent level at Valley is €400 - €450 per m^2 per year. This rent level is higher that the Amsterdam and national average for label A office buildings according to van Manen (2019).

13.4 Labels & regulations

EPC: NEN 7120
When the environmental permit was issued for Valley the building still fell under the current energy efficiency regulation and determination method EPC and NEN 7120. According to the NEN 7120 Valley is energy positive on site for the building-related energy consumption is 224 kWh/m2/year less than the production, resulting in a specific energy performance of -0,309 per m^2.

BENG: NEN 7120 (NTA 8800)

Because the NTA 8800 has not been published at the moment this thesis is written, the old determination method is used for checking Valley's compatibility with the BENG norms. In table 32 the norms and the scores of Valley are presented.

	BENG 1 **Energy requirement** **[kWh/m².yr]**	**BENG 2** **Primary fossil energy consumption [kWh/m².yr]**	**BENG 3** **share renewable energy** **[%]**
2015 - NEN 7120	≤ 50	≤ 25	≥50
EDGE Amsterdam West	**40,1**	**41,4**	**30,8**
2019 - NTA 8800	*Als/Ag* ≤ 1,8 BENG 1 ≤ 90 *Als/Ag*> 1,8 BENG 1 ≤ 90 + 30 * (Als/Ag -1,8)	≤ 40	≥30
EDGE Amsterdam West	**40,1**	**41,4**	**30,8**

Table 32: BENG compatibility of Valley with the BENG norms

As can be seen in table 32 Valley does not comply with both the old BENG norms with the NEN 7120 method and the new BENG norms. The new norms are still calculated with the old determination method. Valley would not be considered a zero-energy office building for the building-related energy consumption within the BENG regulation.

An important addition to this calculation is that Valley is a mix used development: and for each use there are different BENG norms. In this calculation the whole building is calculated according to the BENG norms for office buildings, making the calculation less reliable.

Paris Proof

Valley has a building-related energy demand of 41,37 when the allocation of eternal PV is not considered. An office building is Paris Proof when the building-related energy consumption is less than 35 kWh/m²/year. Because of this Valley is not a Paris Proof building.

13.5 Conclusions & discussion Valley

Valley is an office building which is considered a zero-energy-office building under the current NEN 7120 EPC regulation. However, would Valley have been developed under the BENG NTA8800 regulation it would not have been considered zero-energy. 65% of the energy that is considered renewable energy supply by the NEN 7125: Energy measures at area level is not effective under the BENG regulation.

This allocation of energy that is generated off-site is, from the developer's perspective, a highly cost-efficient solution within the EPC regulation to achieve a better energy performance in the EPC. Compared to the costs of the heating and cooling network, only 15% of the total costs is needed for the external PV, whereas 65% of the renewable energy in the EPC is derived from energy generation from external PV.

The financial and ownership structure of the energy producing systems of Valley makes them relatively risk free for the developer. The two providers of external PV are able to make their investment in the PV system economically profitable due to the contribution to their business case by EDGE Technologies and Eneco will be able to sell their residual heat and cold to the users of the building.

14. Cross-case analysis

14.1 Cross-case analyse part 1: General attributes & technical aspects

In table 33 the general attributes and technical aspects of EDGE Amsterdam West, EDGE Olympic and Valley are illustrated. The first thing that becomes apparent is that the energy required for lighting is relatively the largest energy consumer in all three buildings. More than a third of the building-related energy demand of all three buildings is due to the energy demand for lighting. Secondly, heating for all three buildings is relatively the second largest energy consumer. The percentage of energy that is needed for heating is respectively 27%, 25% and 28% for EDGE Amsterdam West, Olympic and Valley.

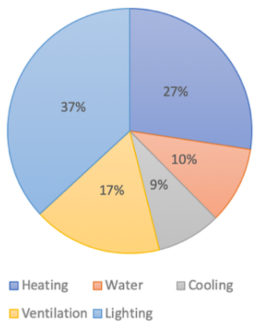
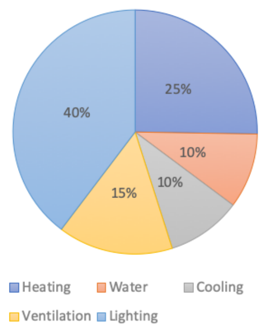
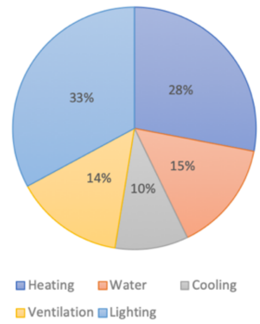
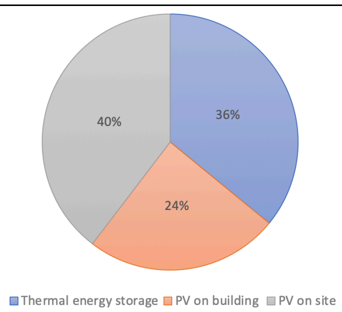
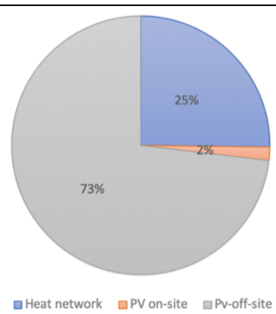
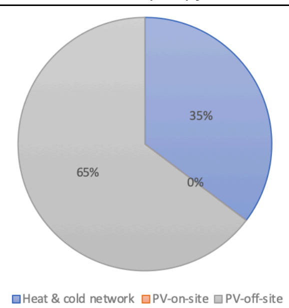
	EDGE West	EDGE Olympic	Valley
General attributes			
Location	Central business district Amsterdam 'Sloterdijk' Redevelopment	Central business district Amsterdam 'Zuid-as' Redevelopment	Business district Amsterdam 'Zuid-as' Newly built
Dimensions	A_{ls} = *Envelope surface = 38.136 m²* A_g = *UFA= 51.066 m²* *B.C.I. = 0.747*	A_{ls} = *Envelope surface = 11.207 m²* A_g = *UFA= 11.716 m²* *B.C.I. = 0.957*	A_{ls} = *Envelope surface = 45.939 m²* A_g = *UFA= 44.538 m²* *B.C.I. = 1.04*
Energy stakeholders	*Main contractor* - G&S Bouw *Contractor installations* - Bosman *Energy advisor* - DWA *Renewable energy supply* – Eneco	*Main contractor* - G&S Bouw *Contractor installations* - Bosman *Energy advisor* - DGMR *Renewable energy supply* – VVE's, Sunrock, Eneco	*Main contractor* - G&S Bouw *Contractor installations* - Bosman *Energy advisor* - DWA *Renewable energy supply* – Bosman van Zaal, Sunrock, Eneco
Technical aspects			
Total building energy demand	2.656.659 kWh/year 52,02 kWh/m²/year	808.295 kWh/year 70,18 kWh/m²/year	2.960.567 kWh/year 66,47 kWh/m²/year
Relative energy demand			
Total energy supply	2.656.883 kWh/year 52,03 kWh/m²/year	808.295 kWh/year 70,18 kWh/m²/year	3.331.672 kWh/year 74.81 kWh/m²/year
Relative energy supply			
Energy systems	*Heating & Cooling:* Thermal energy storage system *Electricity:* PV on roof of the building(s) PV on surrounding plot	*Heating:* Heat network *Electricity:* PV on roof of the building(s) PV-off-site	*Heating & Cooling:* Heat & Cold network *Electricity:* PV-off-site

Table 33: Cross-case analysis of EDGE West, Olympic and Valley part 1: general attributes and technical aspects

The energy distribution of these buildings is interesting. Modern office buildings are known for their facades with a high glass percentage and atria for extra daylight entry. Daylight entry in office buildings is also recognized in literature as an energy-saving measure (Bodart & De Herde, 2002; Li & Tsang, 2008). The office buildings studied here also have relatively high percentages of glass in the façade and use atria for extra daylighting. All this glass, however, reduces the thermal resistance of the building envelope, resulting in higher energy demand for heating and cooling. From the relative energy demands of the studied cases in table 33 it therefore seems as if the extra daylight entry through facades with a high glass percentage is not as effective as commonly assumed.

However, when it is possible to supply the heat and cold for an office building sustainably, this problem of a higher relative energy demand can be solved. All cases use a sustainable supply of heat and cold: EDGE Amsterdam West uses a thermal energy storage system, EDGE Olympic is connected to a heat network and Valley is connected to a heat and cold network. These renewable sources are not always available at every location: there is not always district heating and not every site is suitable for a thermal energy storage source. As a less preferable alternative for the 'renewable' supply of heat is biomass can be considered. Biomass is an energy source which can be used for the sustainable production of heat at available every location according to NTA8800.

As can be seen in table 33 all three buildings are unable to generate enough sustainable energy on a building level to compensate the energy demand of the building. However, of all three buildings electricity is only generated through PV that is on the roof of the buildings, the façade is not used for the generation of electricity. The only building that is fully energy positive on site is EDGE Amsterdam West.

14.2 Cross-case analyse part 2: Financial aspects

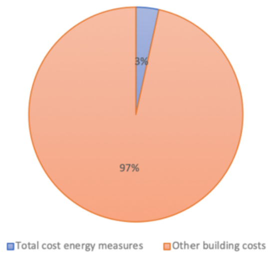
In this part of the cross-case analysis the cases are analysed on financial aspects and structures behind the development. In table 34 the financial aspects of and the compliance with labels & regulations of EDGE Amsterdam West, EDGE Olympic and Valley are illustrated. The first thing that becomes apparent is that the total building costs and the building costs per square meter of Valley are substantially higher that the building costs of the other two cases. These added costs can be explained by the fact that the other two cases are redevelopments, and Valley is a newly built building or the design of the building, which is not repetitive, resulting in many parts that have to individually designed for the building.

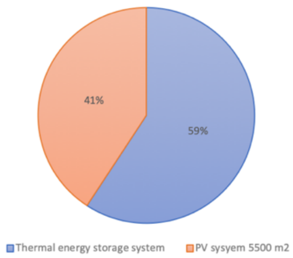
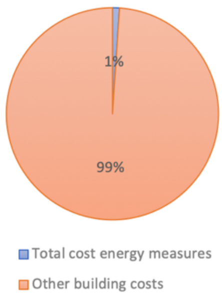
When looking at the construction costs per meter for the different energy supplying measures in table 34 it becomes apparent that the Thermal Energy Storage System of EDGE Amsterdam West has the highest construction costs per kWh of € 1,77/kWh. A close second are the connection costs of the heat and cold network of Valley with € 1,69/kWh.

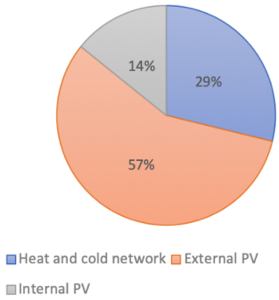
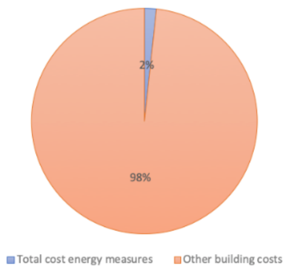
The supply of renewable heat (and cold) is relatively expensive compared to other sources of renewable energy. Side note: in the current structure the Thermal Energy Storage System is the 'cheapest' solution for EDGE as developer due to the sale of the energy system to Eneco.

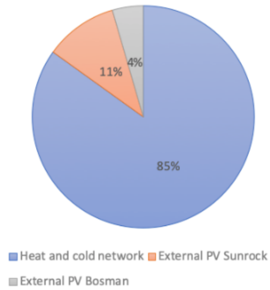
Even though all three cases are located in Amsterdam, the average rental price per square meter per year fluctuates significantly. Something that must be taken into consideration is that these rental prices are the highest in the Netherlands. Due to the high rental prices the business case of these office buildings allows for more room for higher energy efficiency investments.

<table>
<tr><th></th><th>EDGE West</th><th>EDGE Olympic</th><th>Valley</th></tr>
<tr><td colspan="4">Financial aspects</td></tr>
<tr><td>Total construction costs</td><td>€ 82.400.282, -
€ 1.613,59 / m²</td><td>€ 16.399.000, -
€ 1.399,71 / m²</td><td>€ 130.080.000, -
€ 2.920,65 / m²</td></tr>
<tr><td>Relative construction costs

energy supplying measures</td><td>

€ 55,80 / m²

</td><td>

€ 14,99 / m²

</td><td>

€ 49,96 / m²

</td></tr>
<tr><td>Financial structures</td><td>Construction costs
Thermal Energy Storage System:
€ 1.688.138,03
€ 1,77 / kWh

On-site PV installation 5500 m²:
€ 1.161.557,51
€ 0,68 / kWh

Payback periods Eneco
Thermal Energy Storage System:
23.6 years

On-site PV installation 5500 m²:
9.1 years</td><td>Construction costs
Heat network:
€ 50.589, -
€ 0,25 / kWh

On-site PV installation 336 m²:
€ 25.000, -
€ 1,87 / kWh

Off-site PV installation:
€ 43.000, -
€ 0,07 / kWh</td><td>Construction costs
Heat and Cold network:
€ 1.889.351, -
€ 1,69 / kWh

Off-site PV installation:
€ 335.750, -
€ 0,16 / kWh</td></tr>
<tr><td>Local rent levels</td><td>€190 - 250, - / m² / year (2020)</td><td>€300 - €325 / m² / year. (2016)
€400 - €450 / m² / year. (2020)</td><td>€400 - €450 / m² / year. (2020)</td></tr>
</table>

Table 34: Cross-case analysis of EDGE West, Olympic and Valley part 2: financial aspects

14.3 Cross-case analyse part 3: Labels & regulations

In the third and final part of the cross-case analysis the cases are analysed on their compatibility with labels and regulations. In table 35 the compliance with labels & regulations of EDGE Amsterdam West, EDGE Olympic and Valley are illustrated.

EPC: NEN 7120

The first thing that becomes apparent when you look at the row with the EPC: NEN 7120 results of table 35 is that Valley can be interpreted as the most energy efficient building of the three cases. Valley has the lowest value for the EPC of the three cases, which means that according to NEN 7120 Valley generates the most sustainable energy compared to its building-related energy demand of the three cases. When the EPC has a negative value, this indicates that the building generates more energy than it consumes, making the building an 'energy positive' building.

The EPC and NEN do not make a distinction between an office building that is zero-energy on-site or an office building that is zero-energy. If the energy can be allocated to the energy balance of the building according to NEN7125: Energy measures at an area level this results in an improvement of the EPC. Nevertheless, the EPC of a building is of course not the only way people communicate and market the energy performance of their buildings. For marketing to investors and tenants for example, a zero-energy on-site office building can make a large difference with zero-energy office building.

	EDGE West			EDGE Olympic			Valley		
Labels & regulations									
EPC: NEN 7120	EPC 0,000 Energy label A++++ Zero energy on-site office building			EPC -0,002 Energy label A++++ Zero energy office building			EPC -0,309 Energy label A++++ Energy positive office building		
BENG: NTA 8800 (NEN 7120)	***2015 - NEN 7120***			***2015 - NEN 7120***			***2015 - NEN 7120***		
	BENG 1	*BENG 2*	*BENG 3*	*BENG 1*	*BENG 2*	*BENG 3*	*BENG 1*	*BENG 2*	*BENG 3*
	≤ 50	≤ 25	≥ 50	≤ 50	≤ 25	≥ 50	≤ 50	≤ 25	≥ 50
	33,6	0,0	100	39,6	44,4	26,7	40,1	41,4	30,8
	2019 - NTA 8800 (NEN 7120)			***2019 - NTA 8800 (NEN 7120)***			***2019 - NTA 8800 (NEN 7120)***		
	BENG 1	*BENG 2*	*BENG 3*	*BENG 1*	*BENG 2*	*BENG 3*	*BENG 1*	*BENG 2*	*BENG 3*
	≤ 90*	≤ 40	≥ 30	≤ 90*	≤ 40	≥ 30	≤ 90*	≤ 40	≥ 30
	33,6	0,0	100	39,6	44,4	26,7	40,1	41,4	30,8
Paris proof	*Building-related energy consumption:* 0 kWh / m^2 / year *Max building-related energy consumption Paris Proof:* 30-35 kWh / m^2 / year 0 ≤ 30-35 → Paris Proof			*Building-related energy consumption:* 34,59 kWh / m^2 / year *Max building-related energy consumption Paris Proof:* 30-35 kWh / m^2 / year 44,36 ≥ 30-35 ≠Paris Proof			*Building-related energy consumption:* 41,37 kWh / m^2 / year *Max building-related energy consumption Paris Proof:* 30-35 kWh / m^2 / year 41,37 ≥ 30-35 ≠ Paris Proof		

Table 35: Cross-case analysis of EDGE West, Olympic and Valley part 2: labels & regulations.
*: *Als/Ag* ≤ 1,8 BENG 1 ≤ 90, *Als/Ag*> 1,8 BENG 1 ≤ 90 + 30 * (Als/Ag -1,8)

BENG: NTA 8800 (NEN 7120)

The compatibility of the studied cases with the new BENG regulation is checked in two ways. Firstly, the compatibility of the case with the old 2015 BENG norms which are calculation with the NEN 7120 calculation method. Secondly, the compatibility with the new 2019 BENG norms is checked. This calculation is also done with the old determination NEN7120 method, because the new determination norm NTA 8800 is not yet available. The results of this compatibility check are therefore not to be seen as definitive BENG results, but the results do provide insights in the energy performance of the cases that are studied.

As can be seen in table 35 EDGE Amsterdam West is compatible with both the old 2015 BENG norms with the NEN 7120 calculation method and the new 2019 BENG norms and is the only one of the three cases that are studied that is. EDGE Olympic and Valley neither comply with the old 2015 BENG norms nor the new 2019 BENG norms.

This is interesting, because when one would compare the results of the EPC and BENG of the three cases this would give contractionary results of the energy efficiency of the buildings. According to the EPC the most energy efficient office building would be Valley and the least energy efficient EDGE Amsterdam West. According to BENG the most energy efficient office building would be EDGE Amsterdam West and the least energy efficient EDGE Olympic. This shows that the determination methods and norms can be seen as political tools, which work with a set of rules that have been agreed upon by the people that use them. The true energy efficiency of a building cannot be determined solely with these determination methods, the energy efficiency will always be a representation of the reality.

Paris Proof
An office building is considered Paris Proof when the building-related and user-related energy demand is below 50 kWh/m^2/year. When this is translated to the maximum energy demand for the building-related energy consumption an office building is Paris Proof when the building-related energy consumption is less than 30-35 kWh/m^2/year.

Of the three cases that are studied EDGE Amsterdam West is the only building that is Paris Proof. The building related energy consumption is 0 kWh/m^2/year, which is well below 30-35 kWh/m^2/year. Both EDGE Olympic and Valley are not Paris Proof. The building related energy consumptions are respectively 44,36 and 41,37 kWh/m^2/year for EDGE Olympic and Valley, substantially more than 30-35 kWh/m^2/year.

15. Findings emperical research

In this chapter the empirical research is concluded, and the findings of empirical research are presented. For each of the three objects of study in the theoretical framework the sub-research questions are presented and answers are given. The findings and conclusions presented here form the basis for the continuation of this research.

Findings Policies
For the policy section the following sub research question was presented:

How are excising zero energy office developments valued according to current and new regulations?

All three cases studied are considered zero energy office buildings by the current EPC norm and NEN7120 determination method. Under the current regulation (EPC & NEN7120) Valley is administratively considered the most energy efficient office building of the three cases. It has the lowest value for the EPC of -0,309, making the building an energy positive office building.

When the energy efficiency of the buildings is valued with the determination method NTA8800 however, quite different results are presented. Valley and EDGE Olympic do not meet the minimal requirements of the BENG norms and are not considered zero energy. This illustrates the political nature of these policies and proves that the definition of zero energy is different for different norms and determination methods. Only EDGE Amsterdam West is considered zero energy and BENG compliant according to the NTA8800 determination method. One out three studied cases are considered Paris Proof and thereby comply with the goals of the Paris Climate Agreement.

This change in valuation of energy efficiency is caused by the change of NVN2125 'energy efficiency measures at an area level'. This addition to NEN7120 allows allocation of renewably generated electricity from solar energy to be allocated to the energy performance of a building. EDGE Olympic and Valley use the NVN2125 to compensate their remaining energy demand.

BENG 1, which is claimed to be a major improvement according to current regulations because it assures a low energy demand for heating and cooling (DGMR, 2019) looks like the easiest to meet. This finding can be perceived as contractionary, as it does not demand major improvements for the current office buildings. Of the cases that are studied none has a value for BENG 1 that exceeds the limit value for the old BENG norms (2015, NEN 7120) or the new norms (2019, NTA 8800).

Findings technical feasibility
For the technical feasibility section, the following sub research question was presented:

What are the technical characteristics of office buildings that are considered zero energy according to current regulations?

Both EDGE Olympic and Valley would not have been able to be built with their current (technical) designs within the BENG regulation. EDGE Amsterdam West benefits largely from its surrounding plot. Without this plot it would not have been able to have a building related zero-energy on-site energy performance. However, EDGE Amsterdam West would have complied with the BENG norms without the generation of energy on the surrounding plot. This illustrates that it is already possible to develop office buildings which comply with the BENG norms. Because of this, BENG can be seen as a design framework. Some designs, no matter how architecturally beautiful, will not be allowed under the BENG regulation because they are seen as not energy efficient. Some designs, especially with low building compactness indicators, will be not compatible with BENG.

Findings financial feasibility
For the financial feasibility section, the following sub research question was presented:

What are the costs and benefits of office buildings that are considered zero energy according to current regulations?

For the cases studied it becomes apparent that under the NEN7125: Energy measures at an area level the cheapest 'supply' of renewable energy is remote PV. This supply of renewable energy cannot be allocated to the energy performance of the building under the BENG regulation, so it can be assumed that the construction costs for energy efficiency measures will go up due to these new regulations.

The supply of renewable heat (and cold) is relatively expensive compared to other sources of renewable energy. The construction costs of the thermal energy storage system of EDGE Amsterdam West €1,77/kWh for the first year. The investment costs for a heat network are €0,25/ kWh and for a heat and cold network € 1,69/kWh. From a financial perspective the thermal energy storage system is preferable if the system can be sold to an energy operator such as is the case at EDGE Amsterdam West. With this ownership construction the energy system can be a cost neutral aspect of the project. With this construction the payback period for PV is better than for thermal energy storage system, even without the consideration of subsidies such as the SDE+ subsidy.

However, the sustainable supply of heat and cold depends on what is possible on the location of the project. A thermal energy storage system or heat network is not possible for some locations. When this is not possible it becomes increasingly difficult to comply with the BENG norms or to achieve a zero-energy office building.

The cases are all located in business districts of Amsterdam. At the locations market rents are relatively high compared to other parts of the Netherlands. High rents translate to higher property values and therefore more room in the business case for energy efficiency measures. Other locations in the Netherlands with lower gross rental incomes will experience more difficulties complying with the future regulations.

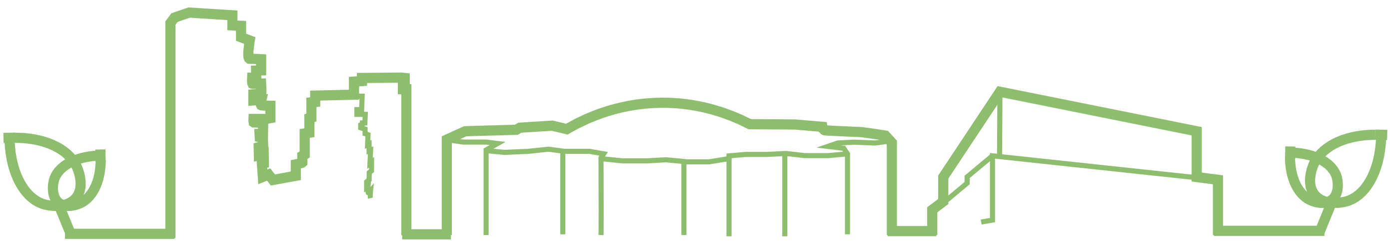
Limitations of case study research
There are a number of limitations to the case study research which will be discussed in this section. Firstly, it must be mentioned that all buildings that are studied are highly energy efficient and considered zero-energy or energy neutral from a certain perspective. The studied cases are not representative of the average energy performance of the building stock. The cases are selected as projects that are commonly seen as progressive office buildings in respect to their energy efficiency.

The data on the energy consumption of the office buildings is collected from EPC calculations. The EPC standard is constructed by the determination method NEN 1720, which is the current energy efficiency determination method for the built environment in the Netherlands. The BENG norms have their own corresponding determination method NTA 8800. However, during the period this research was conducted this determination method was not available yet. Because of this the results of the NEN 1720 calculations are compared with the BENG norms. Because the determination method NEN 1720 is used the results might differ when the NTA 8800 is used for determining the energy performance of the cases and comparison with the BENG norms. Therefore, the results in this case study are not final, but they give an indication of the energy performance of the cases and because the same method is used for the three cases, the cross-case analysis is valuable.

The data on the energy performance of the cases studied is collected from the same type of source: the EPC. However, this does not mean that the actual energy performance of the buildings is equal to the results of the EPC calculations. On the contrary, it is likely that the true energy performance of the cases when monitored gives quite different results than the results from the EPC calculations. EPC calculations are a model or system which the Netherlands has agreed on to use to predict the energy performance of buildings. Measuring the actual energy performance is only possible after the building has been delivered, and there are very few buildings that have sensors that can accurately measure the energy performance. Another problem of the EPC as a data source is that it sometimes feels like a political tool.

Nevertheless, for the purpose of this research the data from the EPC calculations was the only available and most reliable source for the data on the energy performance of the cases studied.

IV. RESEARCH BY DESIGN



16. Design protocol

For the purpose of the third part of this thesis a design protocol is developed and prenented in this chapter. The products of the third part of this research are a technical design for the 'new' zero energy office building within the framework of new policies and redesigns for the studied cases according to this technical design for the 'new' zero energy office building.

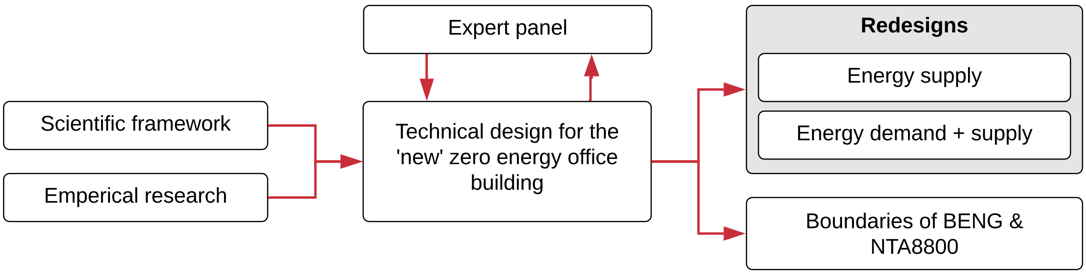


Figure 24: Research by design protocol

Technical design for the 'new' zero energy office building
The technical design for the 'new' zero energy office building emerges from the findings of the scientific framework and empirical research of part I and II of this thesis. Because designing is a cyclical process the technical design is improved and validated by an expert panel focus group.

The technical design for the 'new' zero energy office building serves as a roadmap or technical briefing which can be used by developers during early stages of the development and design process to optimize the energy efficiency of new developments within the framework of the new policies.

Redesign of studied cases
The technical design will be tested by making redesigns for the studied cases. From the empirical research it became evident that the bottleneck between current and new energy efficiency policies is the change in determination of renewable energy supply. Therefore, the renewable energy supply of the studies cases will be redesigned to fit the framework of the new policies. The redesigns will illustrate whether solely changing the renewable energy supply is sufficient for developing BENG compliant, Paris Proof and zero energy office buildings. Due to the scope of this research and the emphasis on the change of renewable energy supply, for two cases a redesign for the renewable energy supply is presented and for one case both the energy demand and supply will be redesigned.

For the complete redesign of both the energy demand and supply the case with the highest average energy demand and worst energy performance of the three studied cases is selected: EDGE Olympic. By redesigning EDGE Olympic according to the technical design for the 'new' zero energy office building the potential of the technical design is demonstrated. This redesign also provides developers an example of how to implement the steps and guidelines of the technical design. The two cases that will be redesigned on their energy supply only, according to the framework of the new policies, are EDGE Amsterdam West and Valley.

Boundaries of BENG & NTA8800
Lastly, the building footprint of EDGE Olympic will serve as the base case for analysing the boundaries of developing BENG compliant, Paris Proof, and zero-energy office buildings within the framework of NTA8800. This analysis is performed with an excel model developed for the purpose of this thesis. This model can be used to illustrate the (design) framework that is formed by the new energy efficiency policies.

17. Technical design for the ‘new’ zero energy office building

This technical design for the ‘new’ zero energy office building is derived from the findings of the literature study and the empirical research. The design is optimized for urban office developments in the Netherlands within the framework of the new energy efficiency regulation BENG and determination method NTA8800. When initiating or analysing a new development the steps and guidelines in this technical design should be followed according to the order in which they are described in this chapter: 1 minimize energy demand, 2 reuse of residual energy flows and 3 renewable energy supply.

17.1 - Energy demand

The energy demand in this technical design is the building-related operational energy demand for office buildings consisting of the energy demand for:

- Heating
- Cooling
- Hot water
- Ventilation
- Lighting
- (De-)humification (if applicable)

In order for an office building to meet the BENG requirements the total building-related energy demand cannot exceed 40 kWh/m^2 per year, to be Paris Proof 30 - 35 kWh/m^2 per year and to be zero energy 0 kWh/m^2 per year. These standards are in accordance with the determination method NTA8800. The energy demand of office buildings is affected by four parameters: the characteristics of the location of the building, the design of the building envelope, the properties of the building materials and the installations. How to optimize these four parameters is described in the following sections.

Location & site characteristics

Although this is a technical design for the ‘new’ zero energy office building, the architectural design should also be taken into consideration to optimize energy performance. Local climate circumstances such as average temperature, orientation to the sun, wind directions and local water resources significantly influence the energy performance of a building. By using smart and bioclimatic design strategies, the energy consumption of a building decreases significantly. Smart and bioclimatic design strategies should be incorporated into the early planning and design stages in order to decrease the total energy consumption, as the most effective energy efficiency strategies are applied before the construction of a building. When smart and bioclimatic design strategies are applied effectively the potential energy saving can lead up to 76.57% (Valladares-Rendón et al., 2017).

Building orientation

The orientation of a building has an impact of on its energy performance. By optimally orienting a building when initiating a new development, the impact of insolation can be avoided during summer and daylight can be harvested during winter. These aspect result in a reduced energy demand for the building. The impact of the building orientation increases with rectangular oblong buildings. As a general rule of thumb: the smaller the surfaces of the building envelope which are exposed to solar radiation, the lower the energy demand for cooling in summer.

In the Netherlands the larger facades of office buildings should be oriented to the south and the north. When applying this building orientation, the larger facades provide daylight and natural heating during the colder winter periods and result in less entry of solar radiation due to the suns higher altitude during the summer resulting in lower energy demand for cooling. With this building orientation energy savings for heating and cooling of 19,76% can be achieved (Valladares-Rendón, 2017).

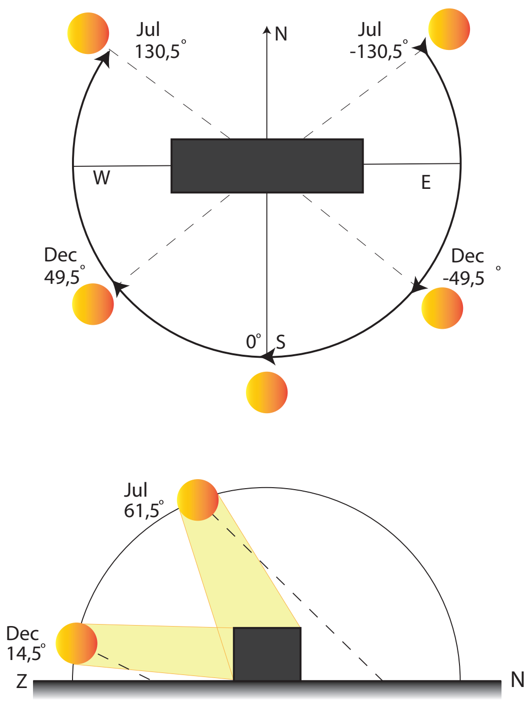


Fig 25: Top view and section of optimal building orientation for an oblong rectangular building in the Netherlands (author, 2020)

Building layout

The layout of office buildings should be optimized to minimize energy demand. To minimize the energy demand for artificial lighting all areas in office buildings that are used frequently and require lighting should be allocated at the zones where daylight enters the building. For a rectangular oblong building without a central atrium as illustrated in figure 26 this is at this at the zones coloured yellow.

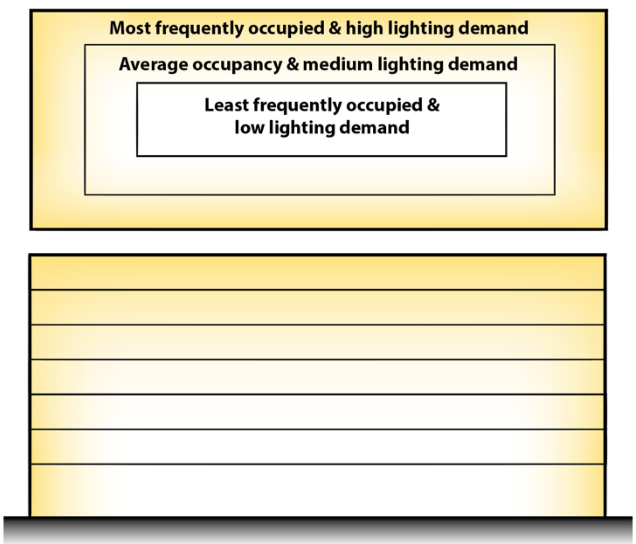


Fig 26: Top view and section for zoning (author, 2020)

Figure 26 presents a floorplan (above) and section (below) of a typical office building. The zones close to the open façade elements in a floor plan harvest more daylight. These zones should therefore allocate activities that require lighting and are most frequently occupied. Zones which do not require lighting and are not frequently used such as support rooms and rooms for staff that are out of office often should be allocated away from daylighting.

At higher floors in urban areas there is more daylight harvesting due to surrounding buildings and trees. Higher floors should therefore allocate activities that require lighting and are most frequently occupied. Lower floors should allocate activities that do not require daylighting are less occupied.

Building envelope

The envelope of a building plays an essential role in the energy performance of a building, as it forms the interface between the interior and the exterior environment. The characteristics of the building envelope that have a large influence on the energy performance are: Window-to-Wall ratio, shading elements and the Building Compactness Ratio.

Window-to-Wall Ratio (WWR)

Due to the climate in the Netherlands the design for the 'new' zero energy office building is heating dominated. This suggests that closed facade elements are favourable compared to open facade elements due to their general higher thermal resistance. However, open facade elements increase the amount of natural lighting in the building, thereby reducing the energy demand for artificial lighting and increasing visual comfort. The Window-to-Wall Ratio (WWR) is percentage of 'open' glazed facade elements compared to the gross façade surface. For office developments in the Netherlands the following Window-to-Wall Ratios are optimal for minimizing the energy use for heating, cooling and lighting (Goia, 2016):

- North facing facades WWR = 43% (39%-45%) Energy saving potential = 19%
- East facing facades WWR = 39% (37%-41%) Energy saving potential = 20%
- South facing facades WWR = 40% (38%-44%) Energy saving potential = 13%
- West facing facades WWR = 41% (39%-43%) Energy saving potential = 18%

The energy saving potentials of the different orientations of WWRs are compared to non-optimal worst case WWRs. Furthermore, these WWRs do not take into consideration shading elements. Therefore, the optimal Window-to-Wall Ratios can change in combination with shading elements.

External shading elements

The amount of solar radiation that reaches the building envelope is of large significance for the energy demand of the building. Buildings that do not use smart shading elements absorb unwanted solar radiation in summer periods resulting in higher energy demand for cooling. When applied in combination with open facade elements shading elements significantly reduce the energy demand for cooling. In general, external shading elements are more effective in reducing the energy demand for cooling than interior shading elements and should therefore be prioritised during the design phases of new developments.

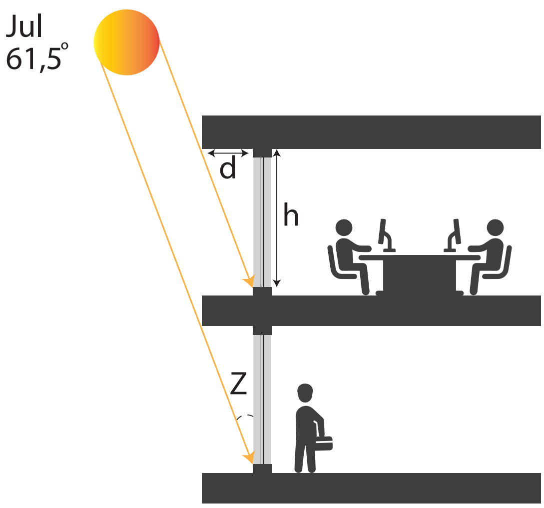


Fig 27: Solar angles for sizing external overhanging shading elements for south facing facades in the Netherlands (author, 2020)

Horizontal overhanging shading elements are effective on facades that are oriented to the South, East and West. Furthermore, for effective shading elements, the angle between the sun and the facade should be known. The formula to ensure that a certain point on the facade is under the shade of shading elements can be derived with from the following equation:

$$h = d / \tan Z$$

Figure 27 presents a schematic view of how this equation should be interpreted for external shading elements of south facing facades. Similar external overhanging shading elements can reduce the energy demand for cooling by 14,81 kWh/m^2 in for the months May to September (Valladares-Rendón, 2017).

Building compactness ratio (BCR)
Regarding the energy performance of newly built buildings the building compactness ratio can play a major role in the overall energy performance of a building. The building compactness ratio is the total envelope surface divided by the usable floor area of building. As a general rule of thumb: the more compact a building, the lower the energy demand of the building.

Building material properties
The properties of the building materials have a large influence on the energy demand of offices buildings. For office buildings in the Netherlands the standards prescribed in the following sections for the properties of the building materials should be used for new developments.

Thermal resistance & insulation
In general, the building envelope should provide high thermal resistance in order to reduce the energy demand for heating and cooling. The thermal insulation of the closed façade elements should have the following standards in the Netherlands (ECOFYS, 2008):

- Closed sections of the outer façade — U-value ≤ 0.15 W/ m^2K (Rc ≥ 6.0 m^2K/W)
- Interior floors and walls to unheated spaces — U-value ≤ 0.19 W/ m^2K (Rc ≥ 5.0 m^2K/W)
- Floor and walls above/against soil — U-value ≤ 0.15 W/m2K (Rc ≥ 6.0 m^2K/W)
- Floor against outdoor air — U-value ≤ 0.13 W/m2K (Rc ≥ 7.0 m^2K/W)
- Roofs — U-value ≤ 0.13 W/m2K (Rc ≥ 7.0 m^2K/W)

The thermal resistance of the open façade elements should have the following standards (ECOFYS, 2008):

- Windows and doors in outer façades (HR+++) — U-value ≤ 0.9 W/m2K
- Horizontal glazing on roof (HR+++) — U-value ≤ 0.9 W/m2K
- Glass fronts/doors to unheated spaces (HR++) — U-value ≤ 1.6 W/m2K.

Compartmentation & infiltration rates
Floorplans of office buildings should be compartmentalized according to the energy patterns of the different functions within the office. By completely separating cold and hot spaces, the cold and hot air does not mix, which increases the efficiency of the overall system and saves energy. Especially in MER and SER rooms, which are the ICT rooms which hold the servers and data for the office, a lot of excess heat is produced. When these spaces are separated by compartmentation the exhaust air is extra hot. Therefore, temperatures in the cooling water system can be increased, which improves the efficiency of the cooling installation. Due to the compatrimentization, the energy demand for cooling is lowered.

When the building envelope is not airtight leakages increase heating and cooling loads in office buildings. In general, the building envelope should comply with an air tightness of < 0.15 $dm^3/s*m^2$ under a pressure of 10 Pascal (qv;10) to prevent increased heating and cooling loads.

Installations
The efficiency of the installations that are needed to operate a building can significantly influence its energy performance.

As a general rule of thumb: all installations should recover as much energy that is going through the system as possible and only operate during working hours. For the HVAC systems this means that heat and cold need to be recovered before the air goes to the outdoor environment. Lighting should only be on during working hours. Buildings should always follow an energy efficient all-electric concept for the installations so that no fossil fuels are needed for operating the buildings.

Artificial lighting
Literature states that 30% of electricity consumed within commercial buildings is used by lighting (Soori & Vishwas, 2013). Of the studied cases lighting is by far the largest energy consumer. 33% to 40% of the total building-related energy demand of the cases is consumed by lighting. The energy demand for lighting is reduced by using natural lighting and by using smart and energy efficient lighting installations.

On average artificial lighting in office buildings is in operation 2400 hours per year (RVO, 2010). By using smart lighting control systems, burning hours can be reduced, resulting in a lower energy demand for lighting. The following lighting control systems should be combined in order to reduce the energy demand (Xu, et al., 2017):

- Multilevel switching
- Manual dimming
- Occupancy sensors
- Daylight linked dimming Lux sensors

When using the above combination of smart lighting systems, the yearly energy demand for lighting can be reduced up to 50% compared to non-smart lighting systems.

To further reduce the energy demand for lighting, areas with different functions within office buildings have different illuminances which are optimal for the type of activities performed in these areas. Artificial lighting should only be used during working hours to supplement daylight according to Lux sensors, after working hours all lighting should be turned off automatically.

For artificial lighting energy efficient LED Lighting Systems of 3.5 Watt/m^2 should be used. These systems consume less energy and produce less heat. The following illuminance standards should be applied during working hours. Natural lighting should be supplemented real time by artificial lighting according to lux sensors:

- Office Areas 500 lux
- Traffic areas 200 lux
- Reception 300 lux
- Support areas (manual switching on, automatic off) 300 lux

HVAC
The energy demand for heating, cooling, and ventilating office buildings is dependent on the energy efficiency of the HVAC systems. Literature states that in Germany the energy demand for heating, cooling and ventilating a building can reach up to 60% of the total annual energy consumption (Mardiana-Idayu, & Riffat, 2012). The heating and cooling of the studied cases is the second largest energy consumer. 35% to 38% of the total building-related energy demand of the cases is consumed by heating and cooling. Of the studied cases the energy demand needed for ventilation is the third largest energy consumer. 14% to 17% of the total building-related energy demand of the cases is consumed by ventilation.

Heat recovery systems can typically recover 60% to 95% of the heat in exhaust air, resulting in reduced energy demand for heating of 20% in cold climates (Mardiana-Idayu, & Riffat, 2012). Furthermore, heating and cooling should be adjusted to the working hours of the office. For office buildings the following heat recovery systems should be applied:

- Fixed plate heat recovery system Efficiency = 50% - 80%
- Rotary wheel heat recovery system Efficiency > 80%

The benefit of fixed plate heat recovery systems is that the system does not allow cross-contamination of air, which is needed for effective compartmentation.

Besides the heat recovery systems occupancy-based HVAC control systems can result in a reduction of energy consumption. 40% of the energy demand for heating, cooling and ventilation in office buildings can be reduced by intelligently using occupancy-based HVAC control systems (Nguyen & Aiello, 2013). In office buildings in the Netherlands it is common in practice to circulate 50 m^3 of air per hour per person. This standard is for the maximum capacity of the building, resulting in wasteful ventilation during quite working hours. The following technologies can be used to determine occupancy of the building, thereby controlling ventilation quantities:

- User entry and exit sensors
- Wireless network logins
- Occupancy sensors

17.2 - Reuse of residual energy flows

Reusing residual energy is needed for lowering or diminishing the energy demand for heating and cooling in office buildings. For reusing residual energy flows developers should start where they have the most control and influence: the building itself. When it is impossible to create closed energy loops on a building level, possibilities in the neighbourhood and city need to be analysed.

Building level

The first step for reusing residual energy flows is attuning the functions within the building with different energy patterns and compartment these functions. The HVAC installations should create closed energy loops when heating and cooling demand complement and supplement each other. The rooms within the office which produce excess heat should be connected with rooms which have a heating demand and areas which have residual cold with a cooling demand so the energy can be exchanged. The building should have a compartmentalized building layout, separating spaces with a heating and cooling demand. When needed to close the system it can be complemented by a thermal energy storage system. These energy storage systems are further elaborated on in the storing section.

Exchanging residual energy within a mix use development

Currently when participating in a tender procedure in the municipality of Amsterdam new developments often have to fulfil multiple functions. Next to the office functions, buildings for example need to include residential and cultural functions. This characteristic of these tender procedures provides opportunities for the exchanging of residual energy flows between the different functions within the development.

Because of the internal production of heat the average office building in the Netherlands currently starts cooling when outdoor temperature is higher than 12 °C. When the outdoor temperature is 12°C residential functions within the development still need to be heated. By using an integral HVAC system in a mix use development with residential and office functions the residential functions can be heated with the residual heat of the office functions, and vice versa. This exchanging of energy will reduce the energy consumption in both the office and residential functions of the development.

Buildings with functions with very specific energy patterns such as a swimming pool should utilize these in the attuning of their building. Besides the large heating demand of (indoor) swimming pools, they can be used to store thermal energy.

Neighboorhood level

When it is impossible to create closed energy loops on a building level, the possibilities in the surrounding area need to be evaluated. This process is called *energy potential mapping*

Energy potential mapping

In general, using residual energy flows with the direct environment of a development requires collaboration with many stakeholders. This is a time-consuming process and therefore it should be started as early as possible in the development process. A new development should analyse the possibilities in the surrounding area for potential use of residual energy, as well as look for buildings which can benefit from possible residual energy of the development itself. This process is called energy potential mapping. To heat and cool office building lower caloric thermal energy suffices and is more sustainable than excising high caloric heat networks. Figure 28 presents a schematic draft for the possibilities of lower caloric heat exchange for the Amsterdam business district South-Axis and the energy patterns of different functions. H is the demand for heating, C the demand for cooling and E for electricity. From energy potential maps, the energy demand offices can be attuned with other functions in the area through three different steps: *Exchanging, Storing* and *Cascading*.

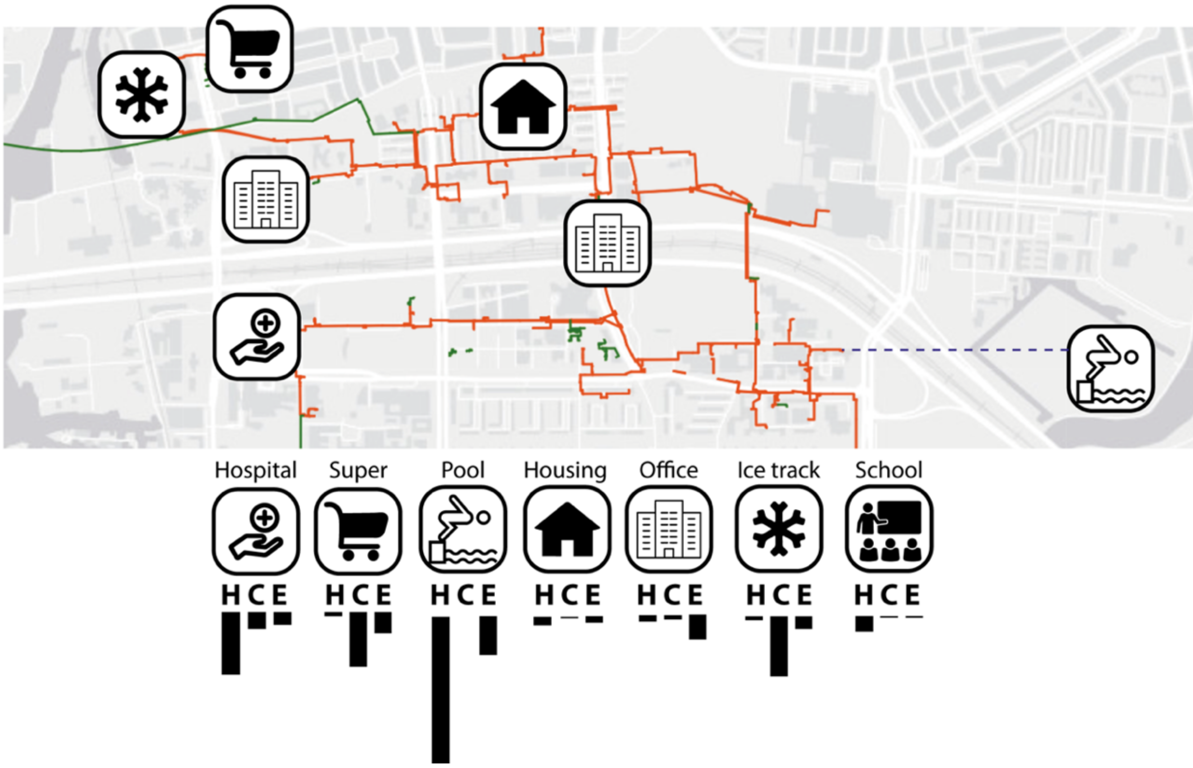


Figure 28: Lower caloric heat and cold exchange Amsterdam South-Axis between different energy patterns (author, 2020)

Exchanging residual energy between buildings

According to an energy potential map such as illustrated in figure 28, office developments can exchange heat and cold with buildings with other energy patterns. When developers start seeing the energy pattern of their developments as integral elements of their environment the residual energy can be utilised. Lower caloric heat and cold grids can be used to exchange residual energy between buildings with different energy patterns to supply office buildings with their heating and cooling demand. When there are facilities with a very specific energy pattern located in the area, such as concert halls, shopping centres, swimming pools or ice tracks, developers should analyse the possibilities of using lower caloric heat and cold grids to exchange heat between these buildings.

Exchanging residual energy flows between buildings is a process which asks for stakeholder collaboration. All different stakeholders need to cooperate, and the municipality should be willing to facilitate the adaption and/or construction of the networks. The municipality of Amsterdam has had a strong sustainability ambition in recent years (2020) and has high standards for its built environment. Cooperation between parties is of essence in the evaluation of exchanging residual energy between buildings. For tender procedures, incorporating the exchange of residual energy between buildings in the area could be the decisive factor, thereby involving the municipality in the execution.

City level
On a city level existing high caloric heat and cold networks can be used to supply office buildings with sustainable heat and cold. Higher caloric heat networks are considered less sustainable and therefore the energy provided by these networks is also valued as less sustainable by the NTA8800. High caloric heat and cold networks should therefore only be used when on a building and a neighbourhood level the heat and cold systems cannot be closed. Figure 29 schematically illustrates the excising high and cold networks for the city of Amsterdam which are supplied by industrial residual heat and surface water.

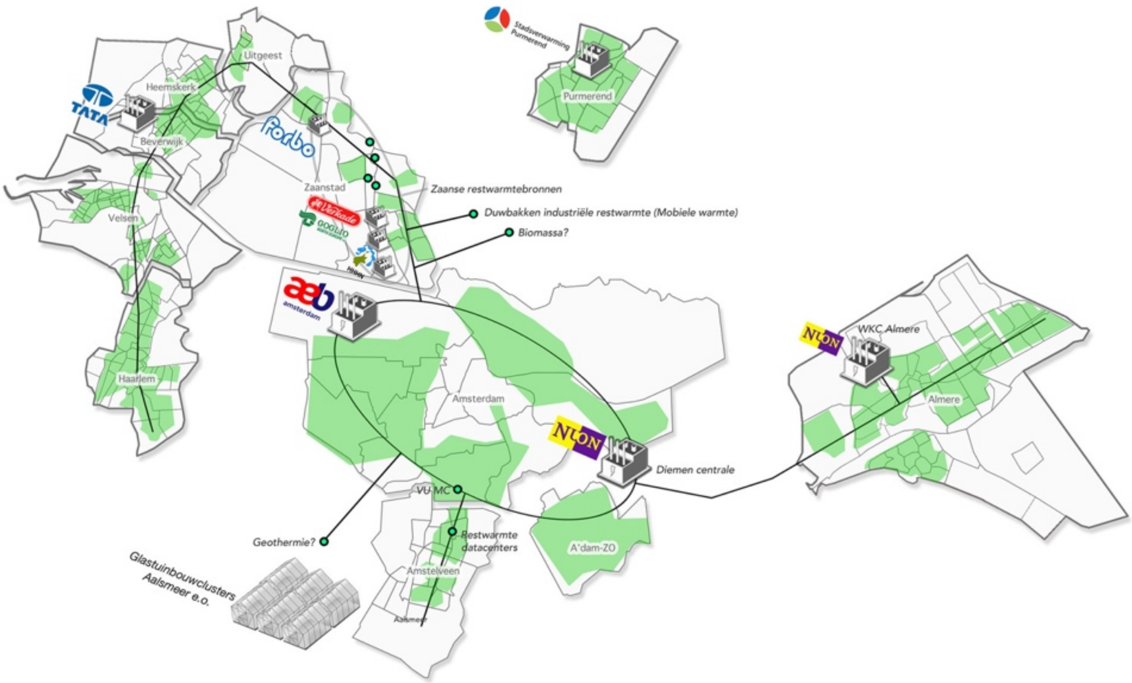


Figure 29: Schematic energy potential map Amsterdam with central heat grids (Energiekaart, n.d.)

Storing
When energy is abundant and demand is low, the storing of energy can provide solutions. Energy storage systems have this purpose of storing abundant energy which can then be drained when there is high demand.

Thermal energy storing
The storing of residual heat and cold can be achieved by integrating thermal energy storage systems in the development's energy system. Not all locations are suited for the construction of a thermal energy storage system due to soil conditions and not every building can have its own thermal energy storage system because this would influence the ground water, resulting in problems for all systems. For every new (re)development possibilities for the storing of residual energy should be analysed. The storing of residual energy is less optimal than exchanging residual energy, because the energy loss is greater when the energy is stored.

Electrical energy storing
Similar to the storing of thermal energy, electrical energy generated renewably on site needs to be stored or cascaded through the electricity grid when there is an abundance during periods of low demand. During period of high demand this electrical energy can be drained from the storage. This peak load management of electrical energy can happen through storing the electrical energy on-site. For storing electrical energy there are two basic options: battery packs and electric vehicles.

Battery packs are the most obvious option for the storing of electrical energy. These batteries are of serious size, depending on the capacity needed for the building, but for a multi-floor office building 'sea container-size' batteries are needed. Furthermore, these batteries have high investment costs. On average the investment costs of these large-scale batteries are €500, - per kWh. When office buildings have Electrical Vehicle (EV) charging station, the batteries of these EV's can be used to store electrical energy. Using the batteries of EV's is a simpler and more economical solution that large-scale batteries.

17.3 - Renewable energy supply

After optimising new (re)developments on the first two steps of this technical design the remaining energy demand needs to be produced renewably in accordance with the NTA8800. For doing so there are two general options that will be elaborated on in the sections below.

Photovoltaic panels

Photovoltaic (PV) panels generate electricity from solar energy. There are two basic categories: industrial PV panels and building integrated PV panels, which are elaborated on in the following sections.

<u>Industrial PV</u>

Industrial PV has lower construction costs than building integrated PV and has higher yields. For an overview of yields and construction costs of PV see table 36. Industrial PV panels are typically installed on the roof of a building and for optimal yields the PV panels are to be oriented to the south under a tilt angle of 35 - 40 degrees and highly ventilated. On average industrial PV panels have a payback period of under 10 years.

The dimensions of industrial PV are typically 990 mm x 1600 millimetre, and when applied on a flat roof the distance between panels should be 2200 mm to prevent shadows falling from one panel to another, under a tilt angle of 35 degrees for optimal yields.

<u>Building integrated PV</u>

Building integrated PV typically has higher construction costs than building integrated PV and has lower yields (table 36). However, building integrated PV has the advantage of replacing building elements such as the façade finish. This characteristic of building integrated PV can compensate the higher construction costs compared to industrial PV.

Building integrated PV is typically installed on the facades of a building, thereby functioning as the exterior finish of the façade. Building integrated PV can take all forms and colours, with darker colours and larger dimensions giving higher yields.

The data on building integrated PV that is shown in table 36 is from dark grey (KSB E1025, RGB 85,92,99) ColorBlast panels produced KameleonSolar (KameleonSolar, n.d.). It is debateable whether panels oriented to the North and North East/North West are feasible and realistic. KameleonSolar advises not using electricity generating panels for facades that have this orientation, but cheaper non generating panels with identical aesthetics.

<u>Overview of yields and construction costs</u>

An overview of yields, construction costs and payback periods is given in table 36. For the payback period of the building integrated PV it should be noted that besides the generation of energy it serves as the exterior façade finish. The construction costs of other 'regular' façade elements should be subtracted from the construction costs of the building integrated PV. In general, the higher the constructions costs of the façade finish that the building integrated PV replaces, the lower the payback periods.

	Industrial PV Roof	BIPV Façade North	BIPV façade NE / NW	BIPV façade East / west	BIPV façade SE / SW	BIPV façade South
Yield [kWh/m²*year]	157	32,685	39,217	67,472	80,194	84,346
Construction costs [€/m²]	€330, - / m²	€430, - / m²	€450, - / m²	€450, - / m²	€450, - / m²	€450, - / m²
Payback Periods [year / m²]	9,6 years	62,6 years	52,2 years	30,3 years	25,5 years	24,3 years

Table 36: Yield and construction costs of PV panels, optimal orientation where applicable.

Biomass-fired boiler plants

Biomass-fired boiler plants (BMBP) generate heat from Biomass energy. There are three basic biomass fuels: pellets, chips and shreds. For office buildings the optimal biomass fuel are pellets (Koppejan, 2016). In general, BMBP is a less preferable solution for the production of renewable energy than PV due to several reasons:

- It can be perceived as less sustainable/renewable because of greenhouse gass emission
- The release of other non-greenhouse gasses such as nitrogen
- Complex logistics for the delivery and storage of Biomass

If an office building has a total heating demand of more than 0.8 PJ a bio boiler greater than 500 kW can be justified. The number of full load hours would be 2,821 per year. In table 37 the data on the costs and energy production of BMBPs is illustrated (Koppejan, 2016). In general, only when the reuse of thermal residual energy from heat networks or thermal energy storage systems is not an option, BMBP should be considered a solution for the supply of renewable energy.

Biomass	Medium	Cost price [€/kWh]	Avoided costs [€/kWh]	Unprofitable top [€/kWh]
A1 pellets	Water	0,093	0,052	0,041

Table 37: Data on Biomass fired boiler plants for office buildings (Kloppejan, 2016).

Heat pumps

Heat pumps can generate renewable heat and cold from renewable sources in the direct environment. Renewable sources in the surrounding environment that can be used are air, surface water and soil. The types of renewable source heat pump systems are described in table 38. Heat pumps are often linked with a Thermal Energy Storage System (TESS) of step 2. The data on combined systems is also illustrated in table 38.

Type	Investment	Annual energy savings
Air source heat pump	€ 10 - €15 per m²	30,56 kWh / m²
Water source heat pump	€700 - €1000 for 5 kW – 250kW €500 - €7000 for 250kW – 1.000 kW	
Heat pump combined with TESS	€ 25 per m² for buildings smaller than 7.500 m² GFA, € 19 per m² for buildings larger than 7.500 m² GFA.	58,33 kWh / m²

Table 38: Data on heatpumps for office buildings (RVO, 2017).

18. Expert panel

In order to improve and validate the technical design for the 'new' zero energy office building an expert panel was organised. During this session the findings of this research are discussed and measured. The protocol for the expert panel can be found in appendix C.

18.1 Selection of members

The selection of the members which are to participate within the expert panel is based on their knowledge on energy efficient (office) buildings. The participants have their expertise in common, but have different professional backgrounds, which can improve the outcome of the expert panel. Different backgrounds can provide different reasoning and solutions to the same problem. Experts with an educational/research background, consulting background and real estate development background participated in the expert panel.

During the execution of the expert panel meeting the world is in the middle of the COVID-19 pandemic. Due to the pandemic governments have taken measures to prevent spreading of the virus, such as the advice against face-to-face meetings, unless strictly necessary. Hence the expert panel meeting was held online.

Name	Organisation
Confidential	TU Delft
Confidential	DGMR
Confidential	DGBC
Confidential	EDGE Technologies

Table 39: Expert panel participants.

18.2 Goal of the expert panel

The goal and purpose of the expert panel is to validate and improve the technical design for the 'new' zero energy office building, described in chapter 17. In preparation of the expert panel all participants received the technical design and were asked to examine and evaluate the document, noting their questions, comments and findings on the content.

During the expert panel the design for the 'new' zero energy office building is openly discussed on the aspects mentioned in the document. Participants are asked to give comments from their professional background.

18.3 Outcome of expert panel

The expert panel meeting was conducted on the 13th of May 2020 through a Microsoft teams call. The topics that were discussed were the following: the energy demand, reusing residual energy flows and the renewable production for office buildings, all within the framework of the BENG regulation. The agenda of the focus group followed the structure of the technical design. During the session the technical design was validated, and improvements were noted by the experts. After the expert panel focus group one of the participants responded more substantively on the technical design by email. These comments have also been processed in the outcomes of the expert panel. After the expert panel focus group, the improvements for the technical design according to the expert panel have been incorporated in chapter 17. The complete outcome and transcript of the expert panel meeting can be found in appendix D.

19. Redesign renewable energy suppy

This chapter presents redesigns for the renewable energy supply of EDGE Amsterdam West and Valley. This approach is chosen to analyse whether current progressive zero energy office buildings can be zero energy within the BENG framework without changing the energy demand of the buildings.

19.1 The current demand of the studied cases

To start this section the current anual energy demand of the cases is illustrated in table 40. The compensation with renewable energy supply is not taken into consideration in this table. This demand is the starting point for this redesign assignment: if the demands can be met by energy production according to the BENG and NTA8800 framework, the redesigns can be considered zero energy. If the demand of the buildings does not meet the local energy production this implies that with these designs the buildings will not be considered zero energy according to the NTA880 determination method, and the energy demand of the buildings will need to be further reduced.

	EDGE Amsterdam West [kWh/m².year]	**Valley [kWh/m².year]**
Heating	14,26	18,64
Warm water	5,29	9,84
Cooling	4,42	6,47
Ventilation	8,88	9,66
Lighting	19,17	21,88
Total	52,02	66,47

Table 40: Energy demand EDGE Amsterdam West and Valley

19.2 Redesign EDGE Amsterdam West

EDGE Amsterdam West with its current design is considered a zero-energy office building according to the NTA8800 determination method and BENG norms. This is because the building has a surrounding plot where PV panels are placed to compensate the energy demand. This theoretical redesign assignment analyses whether EDGE Amsterdam West would still be able to produce sufficient energy without its surrounding plot, because the majority of urban offices do not have a surrounding plot.

For the building-related energy production for EDGE Amsterdam West this redesign implements vertically orientated Building Integrated PV (BIPV). The BIPV elements will replace the existing closed façade finish which are bricks. This redesign has a large impact on the architectural design of the building, but this is disregarded for this assignment. The BIPV panels are dark grey (KSB E1025, RGB 85,92,99) ColorBlast panels with high yields. For further characteristics of the BIPV panels see chapter 17. On the roof 70% of the area will be utilised for placing industrial PV panels. 30% is deemed necessary for other functions on the roof such as installations. The following areas become available for industrial PV on the roof and BIPV for the facades:

Available roof surface	5.554,96 m²
Façade surface East / West	3.706,31 m²
Façade surface South East / South West	976,63 m²
Façade surface South	2.284,67 m²

Utilising these roof and façades surfaces for the renewable production of electricity from solar energy the following theoretical yields can be achieved:

Energy production roof	610.490 kWh / year
Energy production facades	495.040 kWh / year
Total energy production façade + Roof	1.105.530 kWh / year

Energy performance of redesign within BENG Framework
When the proposed measures for the supply of renewable energy are applied to the design of EDGE Amsterdam West the new theoretical energy performance according to the NTA8800 determination method is presented in table 41. As is shown in table 41 the theoretical energy performance of the redesign of EDGE Amsterdam West complies with all three BENG norms. The redesign is also considered Paris Proof, because the primary energy consumption (BENG 2) is below 30-35 kWh / m² per year.

However, the building is not considered zero energy according to the NTA8800 determination method. In order to become zero energy, the building needs to further reduce the energy demand by implementing smart and bioclimatic design strategies for the façade, smart and energy efficient installations and the reuse of residual industrial energy. EDGE Amsterdam West is not able to become zero energy on-site when the surrounding plot is excluded for the generation of energy with its current design and energy demand.

	BENG 1 **Energy requirement** **[kWh/m².yr]**	**BENG 2** **Primary energy consumption** **[kWh/m².yr]**	**BENG 3** **Share renewable energy** **[%]**
2015 - NEN 7120	≤ 50	≤ 25	≥50
Redesign EDGE West	**35,1**	**11,7**	**77,5**
2019 - NTA 8800	*Als/Ag* ≤ 1,8 BENG 1 ≤ 90 *Als/Ag*> 1,8 BENG 1 ≤ 90 + 30 * (Als/Ag -1,8)	≤ 40	≥30
Redesign EDGE West	**35,1**	**11,7**	**77,5**

Table 41: Energy performance of the redesign of EDGE Amsterdam West

19.3 Redesign Valley
The majority of the renewable energy 'supply' of Valley is generated off-site according to NVN7125: 65% of the total energy supply. This renewable energy cannot be allocated to the energy performance of the building according to the NTA8800 determination method of BENG. Therefore, the generation of electricity through vertically orientated Building Integrated PV (BIPV) is implemented in this redesign.

For the building-related energy production for Valley an identical approach as with EDGE Amsterdam West is chosen. The redesign implements vertically orientated Building Integrated PV (BIPV) which replace the existing closed facade finish of natural stone. This redesign has a large impact on the architectural design of the building, but this is disregarded for this redesign assignment. The BIPV panels are dark grey (KSB E1025, RGB 85,92,99) ColorBlast panels with high yields. For further characteristics of the BIPV panels see chapter 17. The roofs of the building are so small that the generation with PV is neglected. The following areas become available for BIPV for the facades:

Facade surface East / West	11.578,60 m²
Facade surface South	2.454,00 m²

Utilising these facades surfaces for the renewable production of electricity from solar energy the following theoretical yields can be achieved:

Energy production facades	938.806 kWh / year

Energy performance of redesign within BENG Framework
When the proposed measures for the supply of renewable are applied to the design of Valley the new theoretical energy performance according to the NTA8800 determination method is presented in table 42. As is shown in table 42 the theoretical energy performance of the redesign of Valley complies with all three of the BENG norms. The redesign is also considered Paris Proof, because the primary energy consumption (BENG 2) is below 30-35 kWh / m² per year.

However, the building is not considered zero energy according to the NTA8800 determination method. In order to become zero energy, the building needs to further reduce the energy demand by implementing smart and bioclimatic design strategies for the facade, smart and energy efficient installations and the reuse of residual industrial energy. Valley is not capable to become zero energy on-site with its current design and energy demand within the BENG framework.

	BENG 1 Energy requirement [kWh/m².yr]	**BENG 2 Primary fossil energy consumption [kWh/m².yr]**	**BENG 3 Share renewable energy [%]**
2015 - NEN 7120	≤ 50	≤ 25	≥50
Redesign Valley	**39,2**	**20,29**	**69,5**
2019 - NTA 8800	*Als/Ag* ≤ 1,8 BENG 1 ≤ 90 *Als/Ag*> 1,8 BENG 1 ≤ 90 + 30 * (Als/Ag -1,8)	≤ 40	≥30
Redesign Valley	**39,2**	**20,29**	**69,5**

Table 42: Energy performance of the redesign of Valley

20. Redesign EDGE Olympic

In this chapter the studied case of chapter 11: EDGE Olympic is redesigned according to the technical design of the 'new' zero energy office building of chapter 17. This redesign is a fictional design for research purposes and will not be executed. The purpose of the redesign is to test the effectiveness of the technical design for the new zero energy office building prescribed by this thesis. EDGE Olympic is chosen for the redesign assignment because it has the worst energy performance of the three cases.

The building will not be redesigned on all the aspects mentioned in the technical design of the 'new' zero energy office building described in chapter 16. This chapter presents examples of redesigns for the studied case that improve the energy performance according to the NTA8800. The technical design serves as a guideline because not all aspects of the design are applicable for every development due to location and building characteristics. This chapter follows the steps of the technical design of chapter 17 and provides redesigns where deemed feasible.

EDGE Olympic is considered zero energy according to the NEN 7120 determination method but according to the new NTA8800 determination method the building would not comply with two out of three of the BENG norms. This bad energy performance according to NTA8800 is caused by two main characteristics of the building:

- Average energy demand per square meter of the building is relatively high, presumably due to missed chances of successfully implementing smart and bioclimatic design strategies
- The majority of the 'renewable' supply is electricity generated outside of the building plot according to NVN 7125 (EMG), which is not valued according to NTA 8800.

The following sections will provide the redesign for EDGE Olympic and focus on improving the two characteristics mentioned above.

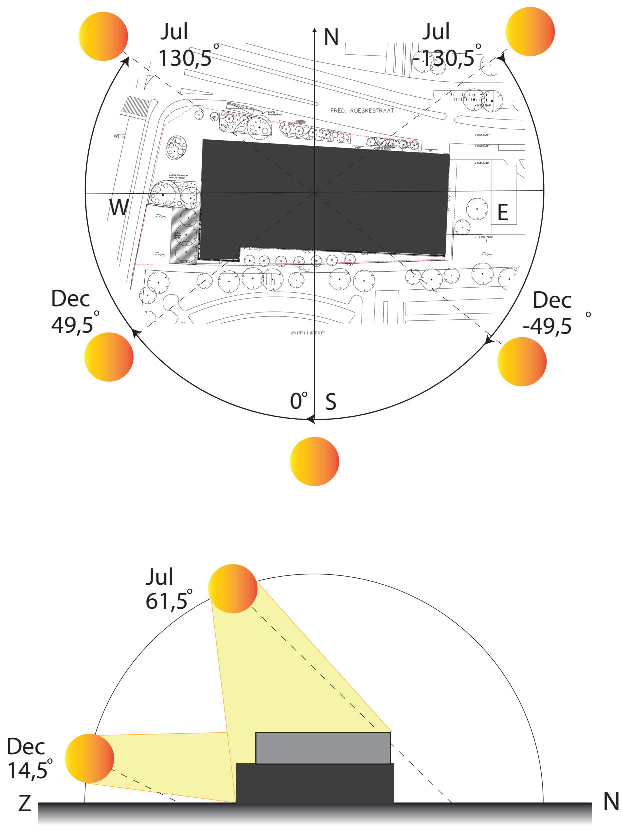


Figure 30: Building orientation EDGE Olympic

20.1 Energy demand

By implementing simple smart and bioclimatic design strategies the energy demand of EDGE Olympic can be reduced. Possible adaptions are discussed in the following sections. The proposed redesigns are options for improving the energy demand of EDGE Olympic, with a minimal impact on the architectural design of the building.

Building orientation and exterior shading elements

The building orientation of EDGE Olympic is optimal, due to the orientation of the plot, which is illustrated in figure 30. The building is a rectangular oblong building, with the larger façades oriented to the south and the north. During the redevelopment of the building two floor were added to the building, consisting of curtain walls. However, the orientation of the plot and building provide opportunities to decrease the energy demand of the building that have not been utilised.

By placing overhanging exterior sun shading elements on the south facades of the building as illustrated in figure 31 solar radiation that enters the building through the open façade elements during summer periods can be eliminated, the theoretical annual energy saving potential for cooling in EDGE Olympic is 3,7 kWh / m² (Valladares-Rendón, 2017), leading to a new annual demand for cooling of 3,28 kWh / m².

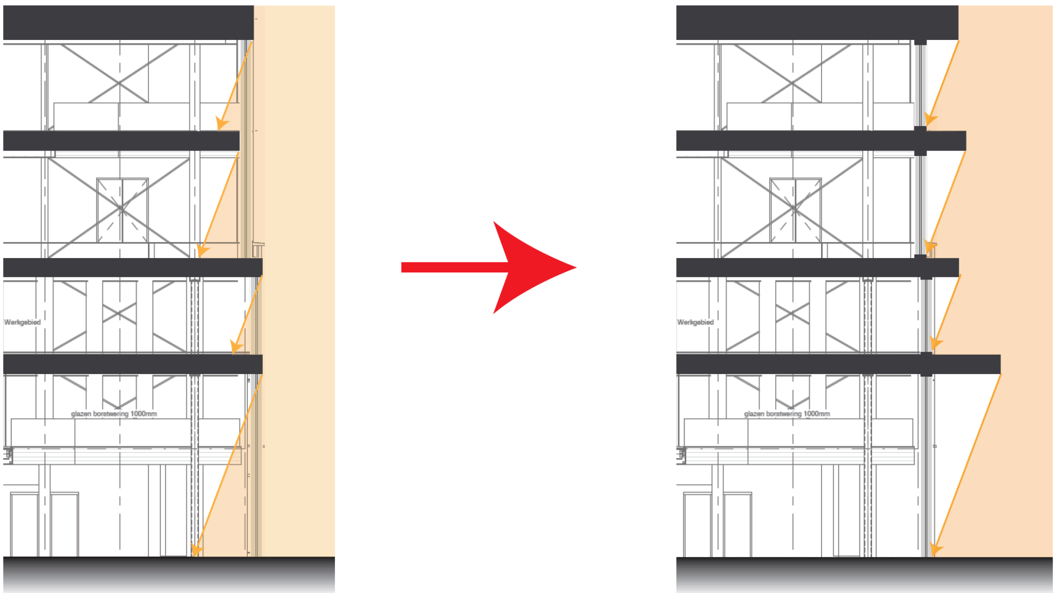


Figure 31: Redesign south facing façades EDGE Olympic with overhanging shading elements (Cie, 2017, altered by author).

Window-to-wall ratio

The window-wall-ratio of EDGE Olympic of the top two floors is approximately 90% in all directions. Optimal Window to wall ratios as prescribed in chapter 16 are the following:

- North facing facades WWR = 43% (39%-45%) Energy saving potential = 19%
- East facing facades WWR = 39% (37%-41%) Energy saving potential = 20%
- South facing facades WWR = 40% (38%-44%) Energy saving potential = 13%
- West facing facades WWR = 41% (39%-43%) Energy saving potential = 18%

When these WWRs are applied to the two top floors of EDGE Olympic the average energy saving potential for heating, cooling and lighting is 17,5%.

Natural ventilation
EDGE Olympic has a Central atrium to provide natural light and air circulation. This atrium however can also be used for natural ventilation by using buoyancy driven ventilation. There is a downside to this buoyancy driven ventilation because EDGE Olympic has relatively wide-open floorplans: draft winds. Therefore, a supplementary mechanical ventilation system is needed in combination with the natural ventilation system. In order to control comfort levels in the building a Building Management System (BMS) is implemented to control the operation of vents. In figure 32 the hybrid ventilation system is schematically illustrated. The hybrid ventilation system in combination with the BMS has a theoretical energy saving potential of 3% for cooling and 30% of the operating time of the mechanical ventilation system due to summer night ventilation.

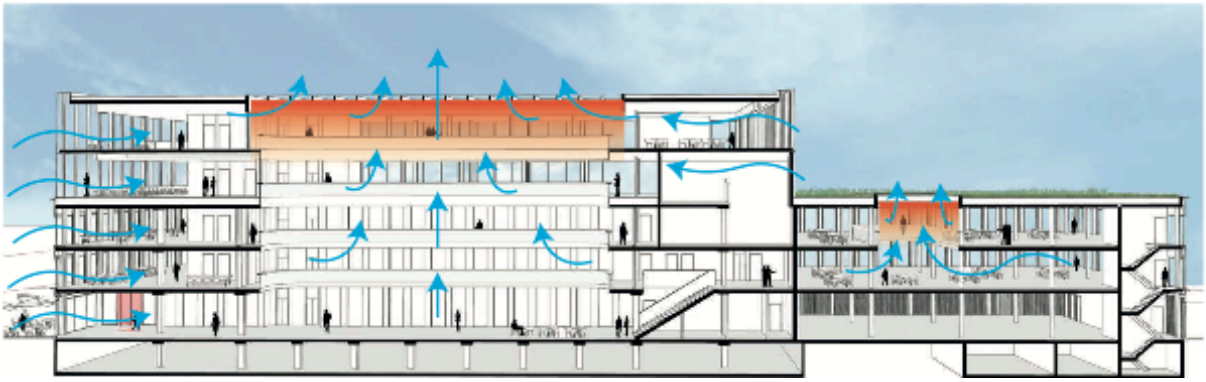


Figure 32: Schematic representation of hybrid ventilation system (Cie, 2017, altered by author).

Installations
EDGE Olympic has a relatively high annual energy demand for lighting compared to the other studied cases: 27,85 kWh/m^2 compared to 19,17 kWh/m^2 and 21,88 kWh/m^2 for EDGE Amsterdam West and Valley. The burning hours of the artificial lighting in EDGE Olympic needs to be reduced by using smart lighting control systems, resulting in a lower energy demand for lighting. The following lighting control systems should be combined in order to reduce the energy demand (Xu, et al., 2017):

- Multilevel switching
- Manual dimming
- Occupancy sensors
- Daylight linked dimming Lux sensors

Furthermore, the illuminance standards of transport should be reduced to the following standards:

	Current / Redesign
- Traffic areas	500 lux → 200 lux
- Support areas	500 lux → 200 lux

Artificial lighting in support areas should always be manually switched on when required. When using the above combination of smart lighting systems, the annual energy demand for lighting can theoretically be reduced to 21,97 kWh/m^2.

Improvement of the energy demand due to redesign measures
Table 43 shows the theoretical energy saving potential resulting from the redesign measures described in the previous sections. It must be noted that energy saving potentials are derived from literature and often established in computer simulations rather than real life testing. According to the redesign f EDGE Olympic can reduce its total annual energy demand from 70,18 kWh/m^2 to 54,27 kWh/m^2, which results in a total theoretical energy saving potential of 25,16% for the building-related operational energy demand of EDGE Olympic.

	Current design EDGE Olympic [kWh/m².year]	Redesign EDGE Olympic [kWh/m².year]
Heating	17,73	14,63
Warm water	6,98	6,98
Cooling	6,93	3,28
Ventilation	10,69	6,41
Lighting	27,85	21,97
Total	70,18	53,27

Table 43: current energy demand and theoretical new energy demand of redesign implications EDGE Olympic

20.2 Reuse of residual energy

EDGE Olympic incorporates the reuse of residual energy flows in its current design. Residual heat of the NUON powerplant in Diemen is used to heat the building by using the existing heat networks in Amsterdam. Lower caloric heat exchange between functions in the area with different energy patterns can further reduce the energy demand for heating and cooling the building. However, because EDGE Olympic already utilises residual energy flows this will not be further analysed during this redesign.

20.3 Renewable energy supply

The majority of the renewable energy 'supply' of EDGE Olympic according to NVN7125 is allocation of electrical energy generated off-site: 73%. This renewable energy cannot be allocated to the energy performance of the building according to the NTA8800 determination method of BENG. Therefore, the generation of electricity through vertically orientated Building Integrated PV (BIPV) is implemented in this redesign.

The BIPV elements will replace the existing closed façade finish which are dark bronze anodized aluminium panels. The BIPV panels will have a similar, slightly darker, colour to minimize the effect on the architectural design of the building while optimizing the yields of the BIPV panels. On the roof of the building 70% of the area will be utilised for placing industrial PV panels. 30% is deemed necessary for other functions on the roof such as installations. The following areas become available for industrial PV on the roof and BIPV for the facades:

Roof surface	2156,2 m²
Facade surface East / West	657,90 m²
Facade surface South	696,50 m²

Utilising these roof and façades surfaces for the renewable production of electricity from solar energy the following theoretical yields can be achieved:

Energy production roof	338.525 kWh / year
Energy production facades	112.967 kWh / year
Total energy production	451.490 kWh / year

20.4 Energy performance of redesign within BENG Framework

When the proposed redesign measures are applied to the design of EDGE Olympic the new theoretical energy performance according to the NTA8800 determination method is presented in table 44. As can be seen in table 44 the theoretical energy performance of the redesign of EDGE Olympic is valued as an energy positive office building according to the NTA8800 determination method. This energy performance is achieved by implementing smart and bioclimatic design strategies for the façade, smart and energy efficient installations, reuse of residual industrial energy and local renewable electricity generation trough PV on the roof and facades of the building. EDGE Olympic thereby complies with both the old 2015 and new 2019 BENG norms.

	BENG 1 **Energy requirement** **[kWh/m².yr]**	**BENG 2** **Primary fossil energy consumption [kWh/m².yr]**	**BENG 3** **Share renewable energy** **[%]**
2015 - NEN 7120	≤ 50	≤ 25	≥50
Redesign EDGE Olympic	**33,1**	**-0,56**	**101,1**
2019 - NTA 8800	*Als/Ag* ≤ 1,8 BENG 1 ≤ 90 *Als/Ag*> 1,8 BENG 1 ≤ 90 + 30 * (Als/Ag -1,8)	≤ 40	≥30
Redesign EDGE Olympic	**33,1**	**-0,56**	**101,1**

Table 44: Energy performance of the redesign of EDGE Olympic

19.5 Financial implications of redesign

In this section the financial consequences of the measures proposed for the redesign of EDGE Olympic are calculated and compared with the financials of the original design. First the financial consequences of the energy saving measures which reduce the total building-related energy demand are evaluated. Secondly the financial consequences of the energy producing measures of the redesign are evaluated and compared with the original design of EDGE Olympic.

Energy saving measures

This section presents the financial consequences of the energy saving measures of the redesign which reduce the energy demand of EDGE Olympic. According to literature additional construction costs of energy efficient office buildings are 0% – 3,3% (Rehm & Ade, 2013). Additional construction costs can be avoided when the energy efficient measures are implemented in the early design phases of the project. The energy saving measures applied in the redesign of EDGE Olympic are minor in construction and material costs and therefore, the assumption is made that they do not cause additional construction costs.

Energy producing measures

Compared to the original design of EDGE Olympic the following energy producing measures were added during the redesign:

- Additional solar panels roof € 686.549
- Building Integrated PV panels facades € 609.480

By using the above-mentioned energy producing measures the following construction costs are avoided:

- Costs for external PV € 43.000
- Costs for façade finish replaced by BIPV € 135.000

This would imply that the additional costs of the energy producing measures are € 1.118.029, -. However, because the redesign measures produce electricity that is consumed in the building, which is not the case with the allocation of external PV, the additional costs for the energy producing measures theoretically pay themselves back by the energy they produce. The following payback periods apply for the energy producing measures of EDGE Olympic:

	Industrial PV Roof	BIPV façade East / west	BIPV façade South
Yields [kWh/yr.]	338.524	42.170	55.809
Investment	€ 686.549	296.055	313.425
Payback Periods	9,6 years	30,3 years	24,3 years

Table 45: Energy performance of the redesign of EDGE Olympic

The average payback period for both the industrial PV and BIPV the total PV installation of EDGE Olympic theoretically is 16,83 years. The average lifespan of high-end office buildings in the Netherlands is 30 years which makes the redesign investment financially feasible with a positive return on investment.

21. Energy efficiency optimisation

21.1 The boundaries of BENG

In chapter 20 the redesign of EDGE Olympic illustrated that is technically and financially feasible to develop zero energy office buildings within the framework of BENG and NTA8800. In this chapter the boundaries of developing zero-energy, Paris Proof and BENG compliant within the NTA8800 framework are further explored.

To do so, the building footprint of EDGE Olympic is used as a base case. This is because some boundaries are needed for the exploration and EDGE Olympic has an optimal building orientation. The energy demand and supply for the building have been established by following the steps of the Technical Design prescribed by this thesis and implemented into an excel model. The excel model is used for analysing the maximum number of floors that are feasible for developing zero-energy, Paris Proof and BENG compliant within the NTA8800 framework, as the limited surface compared to floor area of urban office developments is seen as the major challenge. The model used for this analysis model can also be used for determining the energy efficiency possibilities for new developments. In table 46 the building characteristics of the base case for each floor and the average energy demand are presented.

Building orientation	Optimal: East -West
Length (East - West) [m]	91
Width (North - South) [m]	37
Floor Height [m]	3,4
UFA Floor [m²]	3030
GFA floor [m²]	3367
% roof PV	0,8
WWR	0,4

	Energy demand [kWh/m².yr]
Heating	14,26
Warm water	5,29
Cooling	4,42
Ventilation	8,88
Lighting	19,17
Total	52,02

Table 46: Building characteristics base case zero energy boundaries

In figure 33 the floor height boundaries of office buildings for the different energy efficiencies are illustrated. Figure 33 shows that the boundary for developing zero energy office buildings within the BENG framework is a maximum of six floors. The Roof-to-Facade Ratio (RFR) is introduced by this thesis as a measure to analyse boundaries of zero energy office buildings in the BENG framework. The maximum RFR for still being valued as zero-energy is 0,5 and the corresponding Building Compactness Indicator (B.C.I.) is 0,67.

Figure 33 illustrates that the boundary for developing Paris Proof office buildings is between 10 to 15 floors, where a maximum of 10 floors is for the lower limit boundary of 30 kWh / m^2 per year and a maximum of 15 floors is for the upper limit boundary of 35 kWh / m^2 per year. The maximum RFR for being valued as Paris Proof is from 0,3 to 0,2, and the corresponding Building Compactness Indicator (B.C.I.) is between 0,52 and 0,44.

When the base case is analysed on the boundaries for being BENG Compliant the following findings become apparent. Figure 33 illustrates that there are no boundaries for developing BENG Compliant office buildings when it comes to the number of floors. When the Technical Design for the ‘new’ zero energy office building is applied on the base case infinite floors are feasible for complying with the BENG norms. Because there are no boundaries on the number of floors for being BENG compliant the RFR and B.C.I. are also infinite.

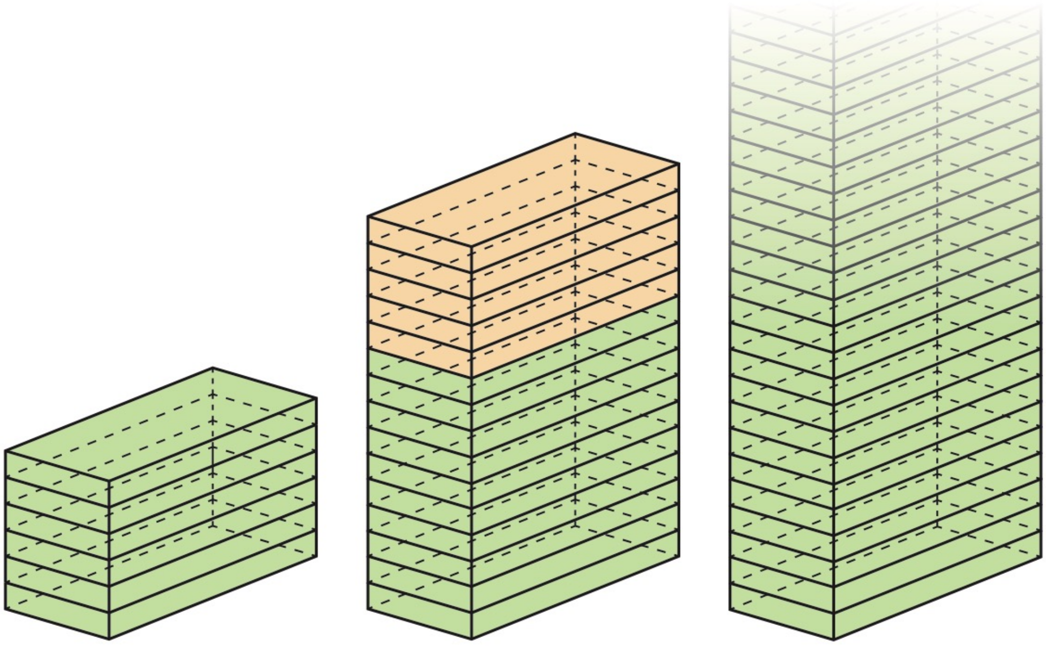


Figure 33: maximum floors for zero-energy, Paris Proof, and BENG compliant office buildings.

The zero-energy office within the framework of new policies

A schematic representation of the design of the modelled zero-energy office building is presented on the next page. The building has a GFA of 20.202 m^2 divided over six floors. On the roof there is a total of 2693 m^2 of PV which uses 80% of the total roof surface. The facades facing East, South and West are covered with 3366 m^2 of BIPV. The annual yields of these installations can be seen on the next page. The renewable energy production of the design illustrated on the next page is higher than the energy demand. This means the design is energy positive on site.

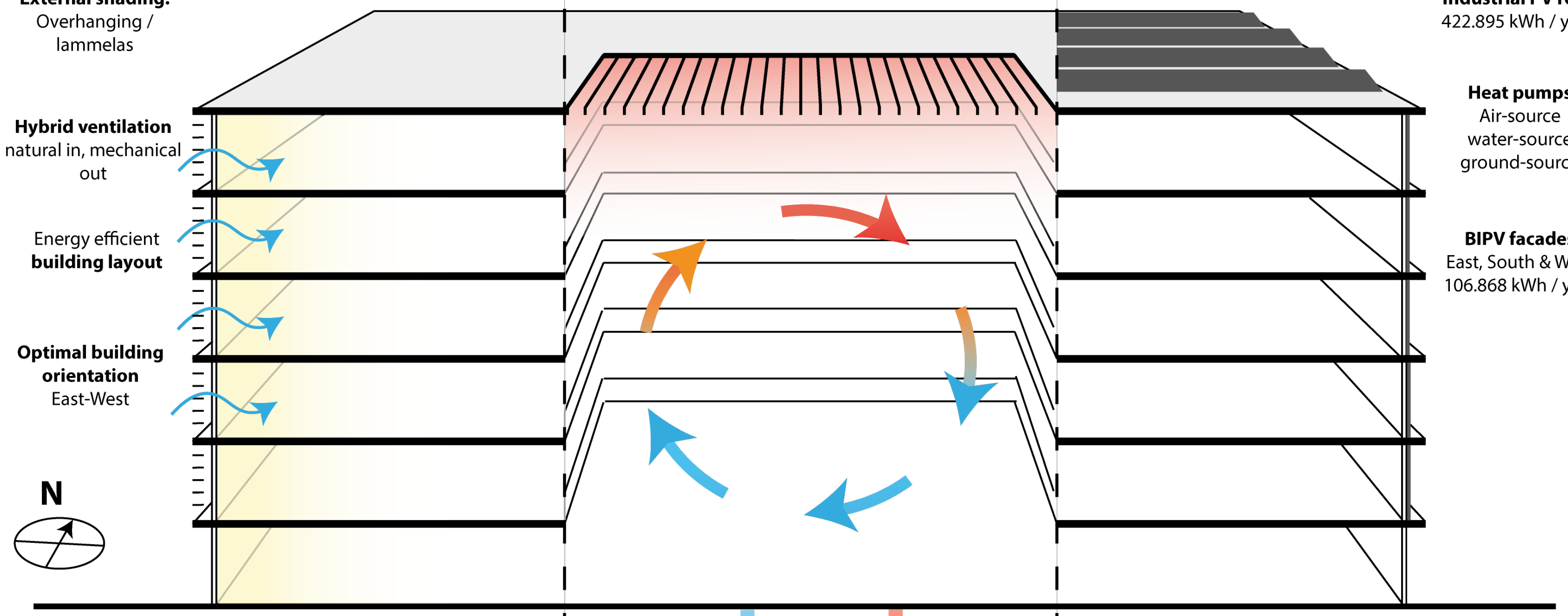
The design of this zero-energy office building has been established by implementing proven technologies and current market standards. Developing zero energy office buildings that are higher that six floors is possible, but for doing so more unconventional technologies such as natural ventilation should be applied. Reducing the market standards for ventilation and lighting can also result in zero energy office buildings of more than six floors.

All the implication of the design for the zero-energy office building have an effect on the architecture. The architectural trend for office buildings is facades that are almost completely composed out of glass. This trend is hard to comply with when developing zero energy office buildings: external sun shading needs to be added in order to decrease cooling loads. The appearance of office buildings will change. Furthermore, almost the complete roof is utilised by PV. Because of this, less room is available for green or a roof terrace.

Reduce energy demand

Reuse residual energy

Produce renewably



	kWh / m2 * year	kWh / year
Heating	14,3	254.281
Warm water	5,29	94.330
Cooling	4,42	78.816
Ventilation	8,88	158.346
Lighting	19,17	341.835
Total	52,02	927.610

	kWh / m2 * year	kWh / year
PV Roof	23,72	422.895
BIPV facades	6,37	106.868
TESS	24,44	113.560
Total	54,52	972.273

22. Conclusions research by design

This chapter presents the conclusions of the third part of this thesis: research by design. For each of the three subjects studied in the theoretical framework the sub-research questions are presented and answers are given.

Conclusions policies
For the policy section the following sub research question was presented:

Can office buildings comply with the new regulations by only changing their energy supply?

Two out of three of the studied cases during this research would not comply with the norms of the new energy regulation BENG with their current designs. The main bottleneck between the current designs of the cases and the new policies is how the renewable energy supply is determined. Therefore, the renewable energy supply of EDGE Amsterdam West and Valley was altered by implementing BIPV on the facades of the buildings.

The redesigns of EDGE Amsterdam West and Valley show that by implementing BIPV on the facades of these buildings the buildings do comply with the BENG norms. This suggests that for large inner-city office developments it is increasingly important to incorporate Building Integrated PV in their designs in order to comply with the BENG norms. By implementing BIPV for generating renewable energy the buildings also become Paris Proof, thereby complying with the goals of the Paris Climate Agreement.

The base case of EDGE Olympic was further analysed on the boundaries for complying with different labels in chapter 21. It became apparent that for developing zero energy office buildings within the NTA8800 framework a maximum of 6 floors is feasible and for Paris Proof office buildings the maximum of 10 to 15 floors is feasible. For developing BENG compliant office buildings there are no boundaries on the number of floors when the technical design is implemented.

Conclusions technical feasibility
For the policy section the following sub research question was presented:

How can zero energy offices be developed within the framework of new energy regulations?

The sole use of renewable energy production on-site through BIPV is not sufficient for developing zero energy office buildings within the framework of BENG. Applying passive and bioclimatic design strategies and thereby reducing the total energy demand of the buildings during early design stages is necessary to achieve zero energy office buildings within the BENG framework.

Using the technical design for the 'new' zero energy office building EDGE Olympic was redesigned, thereby lowering the theoretical energy demand of the building and improving the energy that is generated on site by BIVP.

By following the steps from the technical design for the new zero energy office building it is deemed possible to develop zero energy office buildings within the framework of new energy regulations. To do so however, minimizing the energy demand has to be prioritised from early development and design phases which have a result on the architectural design freedom.

Conclusions financial feasibility
For the policy section the following sub research question was presented:

What are the costs and benefits of developing zero energy office buildings within the framework of new energy regulations?

The investment costs of supplying office buildings with renewable energy generated by BIPV are higher than with the allocation of energy generated outside of the building plot. Table 47 presents an overview of the investment costs and payback period for the current design and redesign of the EDGE Olympic.

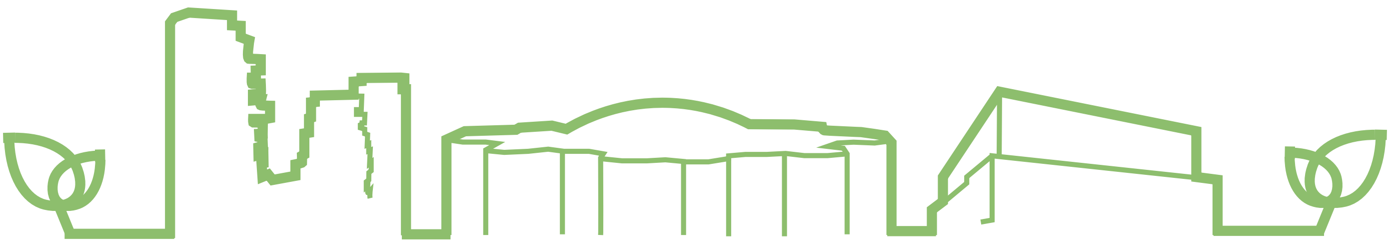
Investment current design	Current investment per m²	Investment costs redesign	Investment costs redesign per m²	Investment increase	Payback period redesign
€ 16.339.000	€ 1,314.06	€ 17.457.029	€ 1.403,98	106,84%	16,83 years

Table 47: Overview of the investment costs and payback period for EDGE Olympic

However, the energy generated by BIPV actually is consumed by the buildings in contrast to when external PV is allocated to the energy performance of the building. Because of this, the buildings have reduced operating costs, which pay back the initial investment back by the energy they produce. The payback period of the total energy producing installation is 16,83 years, which is considered feasible according to the average lifespan of office buildings in the Netherlands and PV installations.

Besides the payback period of 16,83 years for the initial investment of the energy producing measures it may be assumed that the market value of the building also increases when it is considered zero energy according to new regulations. This is because it will become increasingly difficult to develop zero energy office buildings within the BENG framework. Due to increased difficulty fewer zero energy office buildings will be developed, leading to scarcity. When analysed from a simple economic perspective the supply will decrease, demand will stay the same (or increase). This will eventually result in higher market values for zero energy office buildings within the BENG framework.

V. CONCLUSIONS



23. Conclusions

New energy efficiency policies in the Netherlands will change the way office buildings are currently developed. The aim of this research was to provide insights on where the bottlenecks are between current and new policies for the development of zero energy office buildings. The goal of this thesis is to provide insights on how zero office buildings can be developed within the framework of these new energy efficiency regulations. For the purpose of this thesis the following main research question was presented:

How can zero energy office buildings be developed within the framework of the new energy efficiency regulations?

The research consists of three successive parts: a literature study creating a scientific framework for the research subject, an empirical research consisting of case studies of excising zero energy office developments and a research by design resulting in a technical design of the 'new' zero energy office building, redesigns for the cases studied and the boundaries for developing zero energy office buildings within the BENG framework. For the analyses three different perspective were maintained: policies, technical feasibility and financial feasibility.

The findings on the three different perspectives of the three parts of this thesis are summarized in the following sections. This chapter ends with the answer to the main research question.

23.1 Policies

In the Netherlands the new BENG regulation and NTA8800 determination method will replace the EPC regulation and NEN7120 determination method for new developments from the first of January 2021. The new policies are developed because current regulations are not compatible with the goals of the Paris Climate Agreement and European Energy Performance of Buildings Directive (EPBD).

Three main improvements can be identified between current and new regulations: the introduction of BENG 1 which assures a maximum annual energy requirement for office buildings for heating, cooling and ventilation of 90 kWh /m^2 , the disappearance of NVN2125 which currently allows buildings to allocate electrical energy generated outside the building plot to the energy performance of the building and BENG 3 which assures a minimal renewable energy supply of 30% for all new office buildings in the Netherlands. The reason for the disappearance of allocating energy generated outside of the building plot for determining the energy performance of buildings is to stimulate new sustainable technologies and prevent double counting of renewable energy.

However, it is debatable whether these changes in regulation are the major improvements claimed by the policy makers. BENG 1, which assures a low energy demand for heating and cooling (DGMR, 2019) looks like the easiest to meet. All studied cases easily comply with the BENG 1 norm. Furthermore, the exchanging, cascading and storing of energy between buildings with different energy patterns in urban areas can significantly contribute to a zero-energy built environment according to literature (Tillie, et al., 2009). By excluding the possibility of allocation by the NTA8800 determination method the attuning of energy in the built environment is limited.

Furthermore, the new policies BENG regulation and NTA8800 determination method are not a perfectly compatible with the goals and requirements of the Paris Climate Agreement and the EPBD. By signing the Paris Climate Agreement, the Netherlands committed itself to the goal of only consuming renewable energy and having a decarbonized building stock by 2050. The current BENG norms do not meet the goals of the Paris Agreement nor the EPBD. In order for office building to be 'Paris Proof' the maximum annual building related energy demand cannot exceed 30-35 kWh/m^2 which leaves a gap of 10–5 kWh/m^2 with the current BENG 2 norm. The EPBD (2010) states that for the built environment '*energy required should be covered to* *a very significant extent from renewable sources'*. BENG 3 sets the minimum renewable energy supply at 30%. Whether this is a 'very significant extent' is also debatable.

The difference between the new national regulations and the international commitment of the Netherlands to the Paris Climate Agreement and the European EPBD shows that regulations are set to become stricter in the coming years. This thesis therefore introduced the term 'policy independency' which is defined as not striving for the minimal requirements imposed by a policy but exceeding them in a way the policy itself becomes irrelevant. Policy independency will reduce uncertainty concerning energy efficiency regulations for market players.

23.2 Technical feasibility

Of the studied cases Valley has the best energy performance according to current regulations with an EPC of -0,309. According to the new NTA8800 determination method however, it does not have the best energy performance and does not comply with the BENG norms. EDGE Amsterdam West has the worst energy performance according to current regulations with an EPC of 0. According to the new NTA8800 determination method however, it has the best energy performance of the three cases and is considered a zero-energy building. This difference in energy efficiency valuation by the different determination methods shows the political nature of the regulations.

Two out of three of the cases of zero energy office buildings according to current regulations, do not comply with the minimal norms of the new regulations. This large change in valuation is caused by the determination of renewable supply. Of the cases studied that use the allocation of energy generated outside of the plot to compensate the energy demand of the building it in fact forms the majority of renewable energy supply. 73% of the energy supply of EDGE Olympic is generated outside of the building plot and allocated to the energy performance. 65% of the energy supply of Valley is generated outside of the building plot and allocated to the energy performance. EDGE Amsterdam west has the advantage of having a surrounding plot where 40% of the renewable energy is generated.

By redesigning the renewable energy supply of the cases from off-side allocation to vertically oriented Building Integrated PV (BIPV) on the facades of the buildings all cases can comply with the new regulations and the goals of the Paris climate agreement. However, using BIPV for the facade finish of office buildings limits the architectural freedom.

However, for developing zero energy office buildings within the framework of new energy efficiency regulations solely changing the energy supply of office buildings does not suffice. In order to develop zero energy office buildings within the framework of BENG the energy supply and demand of current zero energy office buildings needs to be altered. The largest energy consumers of the building-related operational energy demand are lighting: (33%–40%) heating, (25%–28%) and ventilation (13%–17%). For the development of zero energy office buildings within the framework of the new regulations the 'technical design for the 'new' zero-energy office building' was developed during this thesis. The technical design serves as a guideline and technical briefing for developing zero energy office buildings within the framework of BENG and NTA8800.

EDGE Olympic was redesigned according to the 'technical design for the 'new' zero-energy office building' which resulted in a lower average annual energy demand and an increase of local production through BIPV. EDGE Olympic was selected for redesign because it has the worst energy performance according to the BENG regulation and NTA8800 determination method. The energy demand of EDGE Olympic was reduced by following the guidelines of the 'technical design for the 'new' zero energy office building', resulting in a redesign for EDGE Olympic that is considered a zero-energy office building within the framework of the new energy efficiency regulations. When energy efficiency is prioritised during early stages of the development and design process it is therefore deemed technically feasible to develop zero energy office buildings within the framework BENG and NTA8800.

The base case of EDGE Olympic was further analysed on the boundaries for complying with different labels in chapter 21. It became apparent that for developing zero energy office buildings within the NTA8800 framework a maximum of 6 floors is considered feasible and for Paris Proof office buildings the maximum of 10 to 15 floors is considered feasible. For developing BENG compliant office buildings there are no boundaries on the number of floors when the technical design is used a guidline for developing office buildings.

23.3 Financial feasibility

According to scientific research zero-energy and energy efficient office buildings have higher market values and gross rental incomes compared to non-energy efficient office buildings. Besides these added monetary values of energy efficient office buildings several other added values of energy-efficient office buildings can be identified. Investors increasingly set high demands for their investments and they incorporate Socially Responsible Investments into their investment strategies (PRI, 2018). Highly energy efficient office developments propositions are therefore more likely to receive equity from investors. Furthermore, companies increasingly attach importance to their corporate reputation through their sustainable offices. Developers of sustainable offices therefore have an advantage over their non-sustainable competitors. Moreover, tenants of energy efficient office buildings are more likely to renew their rental contract and are more satisfied (PRI, 2018; Eichholtz, Kok, & Quigley, 2010; ING, 2017; van Manen, 2019).

Allocation of energy generated outside of the building plot to the energy performance of office buildings is a highly costs effective measure for developers to improve the energy performance within the framework of current regulations according to NVN2125: energy efficiency measures at an area level. For the cases EDGE Olympic and Valley which were studied during this research, energy generated outside of the building plot and allocated to the energy performance of the building was responsible for 65% to 73% of the total energy supply. The investment costs of this allocation of energy however is only 1% to 2% of the total investment cost.

During the redesign of EDGE Olympic vertically orientated Building Integrated PV was implemented to replace the allocated energy supply generated outside of the building plot. This redesign of the energy supply resulted in an increase of the investment cost of approximately 6%. However, there is an advantage to the energy supply of BIPV compared to the allocation of energy generated outside of the building plot. The energy generated by BIPV is actually consumed by the building which reduces the operating costs, in contrast to allocation where the generated renewable energy only serves accounting purposes. For EDGE Olympic the combined PV installation has a payback period of less than 17 years. In general, the payback periods for industrial PV on the roof of buildings and BIPV on the facades of buildings is approximately 10 to 30 years. Added investments of energy saving measures can be avoided when implemented during early design phases (Rehm & Ade, 2013).

Because of the new regulations, it will become more challenging to develop zero-energy office buildings. This might lead to less office buildings in the future that are considered zero-energy, even though their energy performance may be an improvement compared to current office buildings. It may be assumed that the stricter determination of zero energy office buildings lead to less zero-energy office buildings and due to this increased scarcity, the value of zero-energy office buildings will increase when the BENG regulation becomes effective.

23.4 Answering the research question

Summarizing the answer to the main research questions of this thesis '*How can zero energy office buildings be developed considering new energy regulations?',* the following main conclusion is drawn from this research:

The current designs of zero energy office buildings as determined by the current ECP and NEN7120 determination method are not compatible for developing zero energy office buildings within the framework of BENG and NTA8800. By following the guidelines of the 'technical design for the 'new' zero energy office building' prescribed in the thesis, zero energy office buildings can be developed wintin the framework of new policies. In doing so, the energy demand should be reduced by using smart and bioclimatic design strategies, smart and energy efficient installations and by reusing residual energy flows (within buildings and within the built environment, for different energy patterns) and generating renewable energy on site. The following starting point should always be implemented for developing zero-energy office buildings within the BENG framework:

1: Minimize energy demand

- Maximize the compactness of the building. The Building compactness indicator should not be larger than 0,67 for developing zero energy office buildings.
- When the site characteristics allow for it, apply an optimal building and façade orientations. For an optimal building orientation, the larger facades should always be faced to the north and the south.
- Implement external shading elements for glass façades. This can be achieved by implementing horizontal overhanging shading elements or lamellas. The cooling loads during summer should be minimized by reducing the amount of solar that reaches glass façade elements.
- Hybrid ventilation systems should be implemented with natural supply and mechanical extraction of air.
- The office should have an energy efficient building layout. For doing so the areas with a high demand for lighting and are frequently occupied should be allocated to areas in the buildings where daylight is harvested.
- The Window-to-Wall Ratio should be between 40% and 43% when no additional external shading elements are implemented.

2: Reuse residual energy flows

- For heating and cooling closed loop systems should be pursued where the energy demand for heating and cooling supplement and complement each other by heat pumps.
- For creating closed energy loops within office buildings compartmentation is essential. Compartmenting areas with different energy patterns and demand prevents the mixture of hot and cold air, which increases the efficiency of the heat pumps.
- When the reusing of energy flows within the building is optimized, but closed systems cannot be realized, possibilities in the area should be analysed by *energy potential mappin*g. Stakeholder collaboration is essential achieving closed systems in an area, so for doing so early communication with these stakeholders and initiative is necessary. Current heat and cold networks are high caloric, and therefore less sustainable, but can also provide solutions for reusing residual energy
- Creating closed heating and cooling energy systems can also being achieved by implementing thermal energy storage systems. Excess heat or cold can be stored in the system and subtracted when there is a demand.
- The storing of electrical energy in batteries can contribute to peak shaving of the electricity production. Electric vehicle batteries can provide for a mobility-building total concept where the batteries provide electricity in the morning when production of PV is low and can be charged during the day when the electricity production is high.

3: Renewable energy production

- Heat pump systems need to be implemented to produce energy from air, water and soil. Furthermore, heat pumps are needed for closing the loop of the heat and cold systems.
- PV systems on the roof and integrated into the facades are needed for the sustainable production of electricity. On the roof high average yields can be achieved during summer and midday. In winter BIPV on facades oriented to the south, east and west have high yields during winter when the sun has a lower angle with the earth's surface and during mornings and afternoons. By combining PV on the roof and facades energy production and demand peaks can be shaved and attuned.

24. Discussion & Recommendations

24.1 Discussion

In this chapter the findings of this research are discussed. First, the theoretical findings are compared with the applicability in practice. Secondly, the limitation, validity and generalizability are discussed and finally the added value of this research is presented.

Theory vs practice

The energy saving and generating potentials discussed and prescribed in this thesis are based on scientific literature and market research. Often there is a gap between the theoretical energy saving and production potential and the actual energy saving and production. In order to find the actual energy savings and production of office buildings they need to be monitored with sensors. Doing this was beyond the scope of this research.

Furthermore, the reusing lower caloric residual energy flows within neighbourhoods is still quite theoretical in nature. The applicability in practice has been tested in Rotterdam with REAP (Tillie, et. Al., 2009). However pinpointing concrete steps for market actors still is difficult due to the reliability on public actors (municipality) to facilitate the heat and cold grids.

For buildings to be Paris Proof the user-related energy consumption needs to be taken into consideration. This thesis focuses on the building-related energy demand. For full determination of 'Paris Proofness' of office buildings user-related energy consumption should be taken into consideration This was beyond the scope of this research.

The studied cases of this research were solely analysed on their energy performance. Other aspects of these projects have been disregarded as this was beyond the scope of this research. When we look at the case studies for example, we find ways to improve the energy performance of Valley. However, the building is, or can be, considered the most architecturally outstanding or pleasing. The building has won many prices from its architecture and is designed by a prominent architectural firm. During the design process the possibilities for BIPV in the corporate facades were analysed and it was decided to prioritise aesthetics above energy efficiency. The technology of BIPV was not as developed as it currently is during the design phases of Valley. Furthermore, on a sustainability level the focus of Valley is more on the biodiversity and social sustainability with all the flora incorporated in the design creating a pleasant living and working area.

Lastly, this research focuses on optimising the energy efficiency of office buildings in the framework of the new regulations. However, in real estate there are always a number of considerations that lead to the product and sustainability can be seen as one of those considerations which has to be realised in a greater or lesser extent. In a way, sustainability in real estate has to 'compete' with other important considerations. Aesthetics is often seen as the counterpart of sustainability, or energy efficiency specifically. Furthermore, sustainability is larger than energy efficiency and aspects as biodiversity and social sustainability also need to be taken into consideration. Valley for instance performs less on an energy efficiency level but has high biodiversity in the design. These aspects also have an impact on the overall sustainability of a building.

Limitations, validity and generalizability of the results

A number of limitations for this research can be identified which are summarised in this section.

All office buildings studied are located in business districts of Amsterdam where the gross rental income is high compared to the rest of the Netherlands. This allows for larger investments in energy efficiency measures. The feasibility of zero energy office buildings on locations with lower rental incomes is not studied during the course of this research, but it is expected to provide challenges.

The data on the energy performance of the studied cases was collected from EPC determinations. As mentioned before the determination has a political nature. Nevertheless, this source was chosen because this source was available for all cases.

The technical design for the 'new' zero energy office building provides guidelines for developing zero energy office buildings up to 6 floors by using proven technologies and market standards. For developing office buildings of more than 6 floors market standards need to be adjusted and/or innovative technologies need to be implemented in the design. Lighting and ventilation are the two types of energy consumers which need electricity to operate. The energy demand for artificial lighting and mechanical ventilation needs to be further reduced for developing zero energy office buildings higher than six floors.

There is a 'catch 22' in the policy independency strategy proposed by this thesis. This is because developers should and want to be policy independent because policies are going to change over time, and it is likely that they will become stricter in the near future. However, it is impossible to be completely policy independent due to the mere fact that policies change. Policies are political instruments which state how certain things are valued, or not. When, for example, high caloric heat networks are not valued as renewable anymore in the future policies, this would mean a change in practice for the development of office buildings, making it impossible to become completely policy independent.

Added value of this research
The BENG regulation and NTA8800 have been developing and changing over the years prior to this research. On the 11th of June 2019 the definitive norms have been presented in a letter to parliament (Ollongren, 2019). This thesis is the first scientific research on the implications of the definitive BENG norms on the development of office buildings. Market players can use the findings of this research for increasing the energy performance of future developments initiatives within the framework of BENG.

Furthermore, this research focusses on the development of zero energy office buildings within the framework of BENG. Current studies on the implications of BENG focus on how to comply and deal with this new energy efficiency regulation. This research takes one step further and looks for the boundaries of developing zero energy office buildings within this regulation and is the first to do so.

24.2 Recommendations

Based on the findings of this thesis there are a number of recommendations for practice, policy makers and future research which are discussed in this chapter.

Practice
Developers should incorporate 'policy independency' into their corporate strategy to become less dependent on the uncertainties surrounding energy efficiency regulations. Besides decreasing the uncertainty around policies, literature states that there are multiple added values of zero energy and highly energy efficient office buildings which give developers an advantage over their competitors. For developing zero-energy office buildings within the BENG framework energy efficiency should be prioritised during the early development and design phases, energy demand should be minimized, and renewable energy should be generated on-site. Developers can use the technical design described in this thesis to develop office buildings that are policy independent.

Policy
There has been a lot of uncertainty surrounding the development of the BENG regulation and NTA8800 determination method: the starting date has been postponed several times and the norms have been changed often. And there still is uncertainty surrounding BENG and NTA8800: the determination software is still not available, and the regulation will become effective the first of January 2021. Market actors should have access to the determination software 6 months before the regulation becomes effective. It is recommended to increase transparency and communication regarding BENG and NTA8800.

This same recommendation applies for the tightening of norms in order to comply with the Paris Climate Agreement and European EPBD. In retrospect it would have been more effective to set norms that are in line with these international agreements from the start. This would have been clearer for market actors, the policy would have been more sustainable and would have resulted in less consumption of energy, materials and effort in the long run.

Future research
For future research the following research subjects are recommended according to this thesis:

- Research on the applicability and stakeholders needed for reusing lower caloric residual energy in neighbourhoods.
- Comparative research on feasibility of zero energy office buildings on locations with lower market rents.
- A research on the possible emergence of negative effects, such as draft winds, by implementing natural ventilation systems in office buildings, and the willingness of investors to abandon current market standards
- Research on how developers can steer and contribute to the use of (office) buildings regarding energy consumption. Specifically, a change in use of artificial lighting in office buildings can contribute to lower energy consumption of office buildings.

26. Reflection

26.1 Research methods

During the process of this thesis a lot of time and energy was committed to the development of a linear programming model, the necessary research to develop the skill of linear programming and performing a literature research on linear modelling. During the final phases of this research it was concluded that linear programming was not a suitable method for creating the technical design for the new zero energy office development. Linear programming was considered not suitable due to the limited solution space for developing zero energy office buildings and the holistic nature of the object of study.

The observation that linear programming was not the right method for this thesis cost a lot of time and heartache. Finding and proposing the alternative research for the design method, which was considered more suitable, would have been a more effective method in retrospect.

26.2 Research process

My personal motivation for the subject of this thesis was to develop more knowledge on the development of zero energy and energy efficient office buildings. In the beginning of this research, the amount of knowledge I possessed appeared to be limited, as the research topic is broad. During the conduction of the thesis my knowledge and applicability of energy efficiency measures and policies grew, thereby fulfilling the personal goal and motivation for this thesis.

During the conduction of this research a global pandemic occurred caused by the virus COVID19. This pandemic had an effect on this research and the graduation internship because all citizens in the Netherlands were told to work from home quarantine. Not having a proper working environment sometimes resulted in reduced concentration, and a change in living situation. In the end concentration and motivation were found in order to complete the research.

Lastly, during the final stages of the research process a part of the research was lost due to a computer error. Although this resulted in stress, the lost writing could be relatively easily retrieved from memory.

I would like to thank my supervisors from my educational institution Hilde Remøy and Andy van den Dobbelsteen for their feedback and brainstorming sessions. The same goes for my supervisor at EDGE Technologies: Constantijn Berning. Without his feedback, constructive criticism and contacts this research would not have been possible.

26.3 Reflection on research topic and findings

The proposed strategies and technical design of this thesis lead to the development of zero energy office buildings when the new BENG regulation becomes effective in January 2021. However, the proposed technical design does have an impact on how buildings will be developed. The current design trend for office buildings is that their facades are becoming more window than wall, leading to office which can be considered 'glass boxes'. These glass boxes are, besides considered aesthetically pleasing, suitable for daylight harvesting. For developing zero office buildings in the BENG framework this trend of glass box office buildings is deemed to change. When large glass facades are part of the design this will need to be in combination with (external) sun shading. When one looks at a building like valley the compactness of a building will also start playing a large role. Furthermore, the integration of PV in the facades of office buildings will change the aesthetics. A common assumption with BIPV is that architects are reluctant to work BIPV as they don't find it aesthetically pleasing. For cooperation with architects the ambitions of becoming zero energy must be communicated very clearly and early during the design process. When the energy efficiency ambitions are formulated early and clearly this provides a clear design framework for architects.

26.4 Relation between graduation topic and master track

Real Estate Management is always conducted within the boundaries of building regulations and these regulations have a large impact on the technical and financial feasibility of individual buildings. Energy efficiency regulations are becoming more and more demanding as the Netherlands is trying to achieve its climate goals. This thesis has studied the relations between these aspects and provided results on the implications of new policies.

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XII. APENDIX

Apendix A: Interview structures & protocols

Technical expert interviews

1. An introductory protocol, with a general introduction of the interviewer and the research that is conducted. The purpose of the research and interview is explained by the interviewer and the interviewer explains what the results of the interview will be used for and how personal data is handled. The introductory protocol ends with the requests of the interviewer for permission from the interviewee to make a sound recording of the interview. This first section of the interview provides the interviewee background information on the interviewer and the research, a ice breaking situation and the interviewer has the opportunity to ask for permission to record interview and use data for research purposes.
2. Secondly, there is a general introduction of the interviewee. Here the interviewee can elaborate on its professional background, what kind of challenges they face during their work and how long they have been doing the work they are currently doing. This section provides the interviewer insights on the reliability of data shared by the interviewee.
3. Thirdly, interviewees are asked about their experiences with and knowledge on the BENG regulation. How and when the BENG regulation will become effective is during the conduction of this research not set in stone yet. The interviewees are working on and with the BENG regulation, therefore their knowledge on the regulation is of interest for this research. Findings on BENG from the literature research are discussed with the interviewees, often leading to new insights.
4. For the third part of this thesis: the operational research, input is needed for the model that is built. The interviewees are in their line of work often working on calculations and models of energy systems of buildings, therefore the knowledge they are able to share on this will increase the researchers understanding of the problem, challenges to tackle and overall feasibility of the model. Interviewees are asked for energy efficiency data for office buildings, key figures and are asked to share their opinion on the approach on the model, provide constructive feedback and share tips. Interviewees are also asked for good sources for key figures, because they work with such data as energy consultants. All the data that is gathered through the interviews with technical experts improves the reliability of the model of the operational research of this thesis.
5. Lastly, interviewees are asked whether they are open to participating in an expert panel to increase the reliability of the results of the research and model. The interviewees are also asked I they are interested in following the progress of the research though mail contact. Questions that arise later can be asked through email after a real-life meeting has taken place more easily. The interview is ended with thanking the interviewee for its participation and time.

Financial expert interviews

1. An introductory protocol, with a general introduction of the interviewer and the research that is conducted. The purpose of the research and interview is explained by the interviewer and the interviewer explains what the results of the interview will be used for and how personal data is handled. The introductory protocol ends with the requests of the interviewer for permission from the interviewee to make a sound recording of the interview. This first section of the interview provides the interviewee background information on the interviewer and the research, a ice breaking situation and the interviewer has the opportunity to ask for permission to record interview and use data for research purposes.
2. Secondly, there is a general introduction of the interviewee. Here the interviewee can elaborate on its professional background, what kind of challenges they face during their work and how long they have been doing the work they are currently doing. This section provides the interviewer insights on the reliability of data shared by the interviewee.
3. Thirdly, interviewees are asked about their experiences with and knowledge on the BENG regulation and whether this would financially affect office buildings. The line of reasoning behind the research of this thesis is explained and interviewees are asked on their personal experiences with the monetary value of energy efficiency measures.
4. For the third part of this thesis: the operational research, input is needed for the model that is built. The interviewees are asked for data on the value of energy efficiency measures for office buildings and are asked to share their opinion on the approach on the model, provide constructive feedback and share tips. All the data that is gathered through the interviews with financial experts improves the reliability of the model of the operational research of this thesis.
5. Lastly, interviewees are asked whether they are open to participating in an expert panel to increase the reliability of the results of the research and model. The interviewees are also asked I they are interested in following the progress of the research though mail contact. Questions that arise later can be asked through email after a real-life meeting has taken place more easily. The interview is ended with thanking the interviewee for its participation and time.

Apendix B: Interview summaries

B1: Energy and Sustainable Building Consultant DGMR

BENG 1
Development of software was outsourced by government to market parties. Development of software proved more difficult that initially thought. That is the reason for postponing the BENG regulation. DGMR is a company working on the software, together with other parties,

With the coming of BENG and the NTA 8800, the allocation of electrical energy that is generated off-site according to the NEN7125: Energy measures at an area level is not valued anymore. This becomes effective when the NTA 8800 becomes effective and replaces NEN7120 in January 2021. There is no optimum in BENG for WWR, if you use more glass your BENG 1 will go up.

There is an exception: When there is a physical link between the system that is producing renewable energy and the building, resulting that the energy that is produced actually is consumed by the linked building, it is possible to have remote production of energy outside of the building plot. This is something what the network operator probably will not support due to safety reasons.

BENG 1 is less strict / adjusted, but the determination is different. Its short-sighted to say they are completely. Market parties asked to raise the bar because the norms were considered too mild. EPBD is the reason to remove the allocation policy. BENG 1 is easiest to comply with. Can run into BENG 1 if you use a lot of glass and do not use sun protection and solar control glazing

BENG 2
BENG 2 is determined by the efficiency of the installations. The only thing that has a directly proportional effect on BENG 2 is PV. This is very difficult for cold heat requirements. Lighting is a direct consumer per square meter.

BENG will only become effective for newly built buildings. Major renovations only have to fulfils building creed conditions for the thermal performance of the building. Major renovations have two aspects: the facade must be exposed, the roof and facades removed, for example. And at least 25% of the building envelope must be adjusted. Major renovations do not have to comply with the BENG norms. For major renovations the following RC values must be met for floor, façade, roof: 3.5, 4.5 & 6 and HR ++ glazing.

For the determination of BREAAM certifications it is still under debate whether the energy efficiency of major renovations will be determined by the NTA8800. Interviewee thinks that remote PV will still be valued for major renovations. EI and or energy label for major renovations.

BENG 3
In terms of policy, biomass is highly valued for non-residential constructions. Only pellets and wood fibres are appreciated in NTA8800 as biomass. BENG 2 can be brought down very quickly by biomass. Often more expensive than alternatives. Policy will most likely changes. Residual heat is valued less effectively than biomass but is valued in BENG 3.

B2: Energy and Sustainable Building Consultant DWA

Relation to projects of developers

How are the energy designs of projects created: does the developer have a certain idea or vision, or do they completely outsource the energy efficiency design?

Many studies in the energy concept based on ambitions of EDGE, regulations and politics. For the supply of heat and cold often the step to thermal energy storage systems is taken.

How are costs of energy efficiency measure indications drawn up?

Data from other projects and sub-contractor installers' budgets.

Very large differences between Thermal energy storage systems in costs and energy yields. Difficult to materialize for a model in excel.

TESS are composed of two components: the sources which are location dependant on how deep to drill. And secondly heat pumps which you always see is air sources heat pump. Comparison between a standard TES and an optimal bivalent system

BREEAM assessment of office buildings within BENG framework

BREEAM will change according to the BENG philosophy. Currently the most point for BREEAM certification can be achieved by energy efficiency. When BENG becomes effective this will be harder because all new buildings will be highly energy efficient. BREEAM currently uses the EPC for the determination of energy efficiency.

Allocation will also be eliminated from the BREEAM determination according to NTA8800. The new bream will be published when the BENG will become effective. Maybe 3 before BENG but thre official BREEAM-NL statement is that they will publish their new determination method when BENG becomes effective.

Facades show large potential for generating renewable energy. Architects often are holding back to implement BIPV into their designs. BIPV on the facades will become necessary in order to develop zero energy office buildings within the BENG framework.

Biomass has a lot of maintenance, odor and susceptibility to failure. Therefore, developers often do not prefer biomass for the sustainable supply of heat. Very large storage capacities are needed.

Energy generated from wind is mostly for appearance. Actual wind yields are too low. Maintenance costs are too high for the yields. Large scale is more feasible, also for PV installations. Wind farms and on sea. The difference between the promised yields of wind systems compared to the actual yields is shockingly low.

Energy performance and EPC

Energy use that comes from the EPC is not the actual energy performance. EPC is a political tool. Returns for certain systems that are politically coloured. Example: there has always been district heating, so this is valued much more positively than it actually is. This is because the government wants to stimulate district heating. Using the EPC as the sources to compare the energy efficiency of different office buildings is acceptable when the political nature of EPC is taken into consideration.

B3: Head of Certification and Project manager 'Delta plan Sustainable Renovation Netherlands'

Expert on the Paris Climate Agreement and its implications for the Dutch building stock. Leads the research which resulted in the implications for individual buildings in order to meet the demand of the Paris Climate Agreement.

DGBC sustainability model for valuations
The DGBC sustainability model has been developed with input from real estate appraisers from the Netherlands. The 'Sustainability model for valuations' of the DGBC should make it easier for building owners and appraisers to gain insight into the sustainability of their property. DGBC strives to make insight into the sustainability of a building as simple as possible.

The obligation of at least label C for office buildings in the Netherlands has accelerated the amount of interest in the sustainability model of the DGBC. This is because banks now assume that it is a risk to finance an office building that does not have a label C.

The DGBC sustainability model is based on 9 points which are similar to the 9 points of a BREEAM assessment, subdivided into the categories: Location characteristics, Object characteristics and Use. In the model, no financial data is linked to the sustainability aspects of the model. The model serves as a tool for appraisers and must be universally integrated with appraiser software, so that there is one list that every appraiser uses to value sustainability. This direct correlation between the sustainability of (office) buildings and the added monetary value they have remains something that is not available yet.

Paris Proof
To be "Paris Proof", an office building may not use more than 50 kWh / m2 / year for the building-related and user-related energy consumption. This number is currently based on the GFA but the DGBC is working on a new calculation where the UFA will be normative. This is because these areas are used in the current energy efficiency calculations for buildings. Some insights on Paris proof buildings:

- The 50 kWh / m2 / year for office buildings is after netting. This means that it is not the total energy demand of the building but the remaining energy consumption after the subtraction of the generation of sustainable energy through, PV, thermal energy storage systems, etc.
- This remaining 50 kWh / m2 / year for office buildings comes from sustainable sources elsewhere in the country: wind, sun on the sea etc. This comes from a calculation where the maximum amount of sustainable energy production in the Netherlands in 2050 is considered and divided relatively amongst all building types.

Remote energy (remote PV) is difficult to maintain and calculate with, so to avoid double counting, this is in those 50 kWh / m2 / year. Therefore, calculating whether an office building is Paris Proof works according to the principles of BENG.

If only the building-related energy is considered for measuring whether an office building is Paris Proof, 30 to 35 kWh / m2 / year must be met.

B4: PhD researcher on Building Integrated PV

PhD

PhD of interviewee is on what roles PV can fulfil in the built environment. Building Integrated PV fulfils two roles: generating energy and serving as a (construction) material. During the PhD the views of architects were analysed on working with PV in their designs. Furthermore, the decision process of using PV in the built environment is studied and analysed.

Solar PV chimney

Besides the PhD research interviewee is developing a (combination of) technologies. This product emerged from the problem of residual heat which come from PV. 20% of solar radiation is transformed into electricity and 80% into excess heat. When PV is used on the facades of buildings it needs to be ventilated in order to maintain its efficiency. PV has 20% efficiency currently in the best-case scenario. The 80% of radiation will be converted into heat which can be used for heating the built environment. The solar PV chimney heats ait from the residual heat from the PV installation which can be used to heat a building.

PVT versus Solar PV Chimney

PVT uses the residual heat by capturing it with pipes filled with water behind the PV. However, some radiation energy is lost on the front of the PVT panel. The solar chimney also captures this energy in the front of the PVT panels because the air wraps the PV cells inside the chimney. PVT on façades of buildings have other complications such as pumping the water up the façade which costs energy. When airt heats up it automatically rises.

BPIV and other renewable energy technologies

Developing offices that are zero energy on site is extremely complicated. Many factors have an effect on the energy performance of buildings: radiation, temperature, weather, etc. Renewable sources should be complementary when they are available: solar energy, wind energy, biomass energy, etc.

Industrial PV can also be placed on the facades of a building. The case of the residential tower on the Sparklerweg in Amsterdam is an example of this. The founder of the architectural bureau who designed this building however, Dick van Gameren, was ashamed of the result according to an interview with the PhD. However, the goal of the project was to design a building that was considered zero energy on-site.

The role of the architect that is using PV in its designs should be further analysed. Architecture it always making compromises between aesthetics, energy and functionality. PhD thinks there still is a problem with the application. The technologies are there. However, we don't know how to use the technologies properly in the building. There should be developed new applications for current PV technologies.

There are some new PV technologies such as Tandem PV. Tandem PV is solar cells on top of each other forming a multijunction which can reach up to 45% -46% efficiency. Problem with these technologies is that they are very expensive.

Number of suppliers of of BIPV to contact for costs and yields of different types of PV:

- Kamelion Solar – Moduls with printed ink
- Zaigzagsolar – facades with angles for higher efficiencies for the PV
- Onyx solar – transparent PV modules

B5: Director development transactions & Executive commercial development director

Quantifying the value of zero-energy buildings
Investors consider the potential of rent compensation when investing in an energy efficient building. The rent multiplied by capitalization shows the market value of a building, as it has a potential higher rental price.

The value for a tenant is based on the ROZ, or triple net basis. With a triple net base all costs are taken by the tenant. Basic rent is paid for a long rental period with single lease back, accompanied by a refurbish plan. Another possibility is than the investor pays for it through a higher rental price. This can be interesting for the investor as the building is energy efficient, the energy costs will be zero and operational and service costs, as a result, can go down. This makes it more attractive and possible for him to pay a higher price for the property. Internally at Edge there is a continuous discussion how to sell the extra value of being energy sufficient to investors. Depending on the suggested construction of calculating the extra worth, the added value comes to either the investor, the developer or the tenant.

One construction of sharing/quantifying the added value is provided. Say a development costs are 100, operational cost can go do by 5%. Therefore, the rent or selling price can increase to 105. As you save 5, this difference can be split between the investor and the developer. There is no such thing as a sustainability premium, so the extra value always comes in the hands of a commercial party, who, in turn can invest it in new projects. Ideally a place for this added value could be a sustainability fund, to keep stimulating research and development.

Energy costs and netting
In theory for energy sufficient buildings the energy costs for tenants can disappear. In general, this means a decrease of 1/3 of the service costs. This is a very clear and provable consequence. Paying a higher price for renting an energy sufficient office is something both a tenant and investor should be willing/accept to pay. There is no clear answer on how to quantify the added value of being energy sufficient. Internally developers also struggle with this proposition.

Having lower service costs can be competitive. If you can add a part of this extra value into your rental price, you will have a higher market value. However, both experts discuss that once your energy bill is neutral, the service costs may not be determined by energy usage, but for example through depreciation of batteries or so. Something else can and will fill the place of energy usage costs. Regarding energy management that will be a big issue that the market is not yet aware of.

Scarcity
The scarcity among energy efficient offices, can also have a value increasing effect. There are few energy efficient offices, and investors see having an energy efficient office as prestigious and unique. However, quantifying the added value remains a big issue. Especially when you need to distinguish where this worth is made out of. This can be the BREEAM label or the actual energy positivity/neutrality, but that is difficult to state.

You can distinguish yourself for having an energy efficient or sustainable office, like The EDGE. This scarcity will increase demand and thereby the liquidity of the products. As there is no day trading in buildings, trading only occurs once every 5 or 10 years.

Taxation
Currently all appraisers need to include an extensive sustainability report and taxation paragraph. Having that report also provides value, because it creates liquidity to a product.

Day trading, or quantifying the value of an energy efficient building, could be based on the taxation value. This holds tangible proof. For funds taxation happens every three months in other situations once every year. These taxation reports could help quantify the worth as you are able to compare renovated, or new energy efficient buildings to non-energy efficient buildings. Quantifying the worth could be discussed by comparing the value of buildings with different energy labels, new BREEAM labeled and BREEAM-in-use labels within the same city. However, with the need to compensate for time, scarcity and other developments in the market this would become an almost impossible analysis. Even when doing all these corrections and comparisons you would never be able to get a very concise answer.

Emotion versus facts
It remains difficult to state how to specifically quantity any increased value of being energy efficient as an office. Showing cost reduction will most likely remain most tangible for the price people are willing to pay. It always comes down to the way you sell it as a developer. Playing into the emotion of the buyer could also be part of the strategy. For example, one could picture alternative buildings as potentially being one of the most polluting buildings within 3-4 years, because other buildings *will* take the step to become more sustainable. As the industry changes, your sales strategy changes with it.

Financial pressure
It is very likely that in the near future banks will stop funding non-sustainable buildings. Discounts will be given for developing sustainable buildings. Those buildings will be backed up financially and therefore be liquid. In order to build non-sustainable buildings, you will need to have much more private equity.

BENG versus existing buildings
Renovating existing buildings into energy efficient buildings will become almost impossible with the new legislation. When considering buildings like The Valley, the shape and design of the building is too limiting. Legislation will play a determining role when it comes to design. The design of the building needs to be adjusted in such great measures in order to become energy efficient that this will interfere with the existing design. There is always the need to find balance in the finesse of the design and doing everything possible to become energy sufficient in order to keep the rental price in balance. For example, offering sufficient daylight is a must and cannot interfere too much to keep rental prices stable.

BENG also limits many potential solutions of using generated energy more efficient among neighborhoods. For example, connecting an entire neighborhood to the thermal energy storage system. It is not allowed as you may be seen as an energy provider. Technically it is possible, however on a neighborhood level it is not feasible. Fragmented politics make things unnecessarily complicated. The expectations set by the government should be realistic. Every stakeholder needs to contribute in some way. It would be unfair to only expect innovation from commercial parties.

Good to look into elements that are very new and have big potential for meeting the BENG legislation, like Biomass and hydrogen homes.

Apendix C: Expert panel protocol

Introductie

<u>Toestemming opname</u>
Allereerst zou ik willen vragen voor uw toestemming om deze sessie op te nemen. De opname zal enkel gebruikt worden voor wetenschappelijke doeleinden. Indien u dit wenst zal u naam niet genoemd worden in het uiteindelijke verslag. **(Aangeven in voorbereidende mail)**

U heeft allen het technische ontwerp/ stappenplan van het 'nieuwe' energie neutrale kantoor van mij toegestuurd gekregen en de tijd gehad deze te bestuderen. Ik zou u willen vragen om het ontwerp/ stappenplan voor u te nemen zodat wij gezamenlijk door het plan heen kunnen gaan om vervolgens openlijk jullie bevindingen en commentaar te bespreken.

Ik zou u willen vragen om uw vragen, commentaar en bevindingen bij de toebehorende secties van het ontwerp/ stappenplan te opperen, zodat deze in de groep besproken kunnen worden en daarmee mogelijk een discussie tot gang komt. Daarnaast wil ik u aanmoedigen om de vanuit uw vakgebied mogelijke obstakels toe te lichten, om zodoende tot passende oplossingen te komen.

<u>Doel van deze sessie:</u>
Verifiëren en verbeteren van de gestelde stappen, constateren wat er nog ontbreekt en verfijnen van de gestelde uitgangspunten. Om zodoende bij te dragen aan de hoofdonderzoeksvraag van deze scriptie.

<u>Hoofd onderzoeksvraag thesis:</u>
Hoe kunnen energie neutrale kantoren ontwikkeld worden als we de nieuwe regelgeving in acht nemen?

Vragen

1. energievraag
<u>WWR & zonwering</u>
Uit literatuur komen optimale waardes van 40% - 50% voor de Window-to-Wall ratio's die leiden tot een verminderde vraag van 13% - 18% voor het verwarmen, verkoelen en verlichten van kantoren. In deze onderzoeken wordt echter niet rekening gehouden met externe overstekkende zonwering.

- Wat is naar u mening de invloed van deze zonwering op de WWR?

Natuurlijke/ hybride ventilatie
Natuurlijke of hybride ventilatiesystemen kunnen bijdragen aan een verminderde energievraag voor ventileren in kantoren. Door natuurlijke ventilatie kunnen echter ook trekwinden binnen kantoren ontstaan.

- Wat zijn concrete stappen om trekwinden te voorkomen bij natuurlijke / hybride ventilatie?

2. Hergebruik van reststromen

- Welke actoren zijn er nodig om het uitwisselen van lagere calorische warmtestromen binnen stedelijke gebieden mogelijk te maken?
- In hoeverre zijn de warmtenetten (in Amsterdam) klaar voor het transporteren van lagere calorische warmtestromen?
- Wat zijn in uw ogen de benodigde stappen voor marktpartijen om in samenwerking met de gemeente het uitwisselen van reststromen met gebouwen in de omgeving te concretiseren?
- Wat zijn momenteel de belangrijkste knelpunten voor het mogelijk maken van het uitwisselen van lagere calorische warmtestromen?

3. Duurzame energieopwekking

Door het wegvallen van de allocatieregeling binnen BENG zijn er nieuwe technieken nodig om tot energie neutrale kantoren te komen. Twee van deze technieken zijn Building Integreted PV voor elektrische energie en Biomassa voor warmte.

BIPV

	Industrial PV Roof	BIPV Façade North	BIPV façade NE / NW	BIPV façade East / west	BIPV façade SE / SW	BIPV façade South
Yield [kWh/m²*year]	157	32,685	39,217	67,472	80,194	84,346

- In hoeverre acht u de waardes voor energieopwekking hierboven realistisch?
- Acht u BIPV noodzakelijk om tot energie neutrale gebouwen te komen binnen BENG?

Biomassa Boilers

- Acht u Biomassa boilers noodzakelijk om tot energie neutrale gebouwen te komen binnen BENG, als andere duurzame alternatieven zoals WKO en stadswarmte niet mogelijk zijn?
- In hoeverre acht u biomassa boilers haalbaar binnen een kantoorgebouw?
- In hoeverre acht u biomassa een duurzame oplossing voor de opwekking van warmte?

4. Open opmerkingen

- Zijn er nog aspecten die ontbreken in het technische ontwerp om tot energie neutrale kantoren te komen binnen BENG?
- Andere opmerkingen?

Agenda

13 mei 2020

12:00 – 13:00

Tijdstip	Onderwerp
12:00 – 12:05	Binnenkomst
12:05 – 12:10	Introductie
12:10 – 12:25	Energie Vraag kantoren - Window to Wall in combinatie met externe zonwering - Hybride ventilatiesystemen & trekwinden - 3,5 Watt verlichting in kantoren ook haalbaar met oog op comfort?
12:25 – 12:40	Hergebruiken van reststromen - Actoren - Inzetbaarheid van huidige warmtenetten voor laag calorische warmte - Benodigde stappen voor marktpartijen - Belangrijkste knelpunten
12:40 – 12:55	Duurzame opwekking - BIPV - Biomassa boilers (pellet kachels)
12:55 – 13:00	Ruimte voor open opmerkingen en discussie & afsluiting

Apendix D: Expert panel outcome

The expert panel meeting was conducted on the 13th of May 2020 through a Microsoft teams call. The topics that were discussed were the following: the energy demand, reusing residual energy flows and the renewable production for office buildings, all within the framework of the BENG regulation. The agenda of the focus group followed the structure of the technical design. After the expert panel focus group one of the participants responded more substantively on the technical design by email. These comments have also been processed in the outcomes of the expert panel.

Part 1: Energy demand

WWR & Sun shading

In the NTA8800 determination method there is a linear relationship between the energy demand for heating and cooling conform BENG 1 and the open façade elements. Increasing the amount of open façade elements (windows and doors) will increase the BENG 1 score.

The technical design indicates optimal Window-to-Wall Ratios by the definition of open divided by closed façade surfaces. Open façade elements are defined as doors and windows. Definitions for the determination of WWR can vary. One of the participating experts usually works with WWR = (Window surface / (Window surface + closed)). The definition of WWR at Edge Technologies, however, is WWR = (open / gross facade surface). These definitions give completely different ratios. Although the technical design clearly indicates the definition, the participating expert doubts whether it is the correct definition. After the question what of the effect of the WWR is in combination with external sun shading it was replied that this is hard to pinpoint for a general technical design for office buildings.

Natural / hybrid ventilation

For concrete steps on reducing the effects of draft winds cause by natural / hybrid ventilation an expert referred to the Energy Academy Europe building of the national University of Groningen. In this case hybrid ventilation is used for cooling and ventilating the building.

For the expert with a background in real estate development the comment was made that from the market there are high demands for comfort and ventilation imposed by institutional investors. This forms a restriction for developers such as EDGE Technologies for applying natural and/ or hybrid ventilation systems. Investors, often with limited knowledge on the energy efficiency of buildings, cling to the advice from external consultants and market standards. A new question was raised from the expert with a background in real estate development: Are there negative effects of natural / hybrid ventilation for the comfort level in office buildings and if so, what are these negative effects?

Low wattage artificial lighting / smart heating installations

The question was asked whether 3,5 watt / m^2 artificial lighting be used for artificial lighting instead of 5 - 6 watt / m^2, without harming the comfort levels. One expert replied that 3,5 kWh results in less excess heating which is considered favourable. The amount of lux can be determined, and this more efficient than with regular halogen lighting. These new 3,5 watt / m^2 Led lighting can produce 500lux lighting. However, the even distribution of light with 3,5 might form problems

It was also stated that implementing smart heating, cooling and lighting systems is more effective for reducing energy demand than applying highly efficient installations. These smart systems were already part of the technical design presented to the expert panel. Additional options for smart heating, cooling and lighting that were proposed during the focus group:

- Occupancy based desk heating which can also improve personal comfort
- Workspace lighting

Comment from expert with development background: 'The operation of offices has a large impact on the energy demand for lighting. The developer is not responsible for how the building is used. When users of buildings are more aware of the energy consumption of lighting large reductions energy the energy consumed by lighting can be realised. Currently lighting is left on all night for safety reasons, which is ridiculous from an energy perspective

Part 2: Reuse of residual energy flows
Current heat networks are unsuitable for exchanging and cascading of lower caloric heat. Lower caloric networks need smaller tubes for transporting the water and only small distances can be travelled. Long distance will result in too much energy loss. One of the experts proposed the following additional steps for optimizing the reusing of residual energy flows in office buildings:

Reusing energy on a building level
The first step for developers is to optimize the reusing of residual energy flows on the level they have the largest influence and control: the building level. The following steps should be taken to optimize the reusing of residual energy flows within office buildings:

- Understand your programme and energy pattern: is it monofunctional or multifunctional?
- Design your technical system according to the programme and energy pattern using the energy shortages and surpluses. Compartmentalization of spaces in office buildings is important. Zones within the office that need cooling and areas that need heating can exchange energy by using heat pump like systems. Match the energy patterns of different functions within the building with one energy system. By applying this system, the demand for heating and cooling can be solved.
- This system can be combined with a thermal energy storage system when necessary.
- Recover heat and cold when air and water is leaving the building.

In practice the reusing of energy on a building level is currently not fully optimized. The reason given was the difference in option of the developer and the user of the building. The developer designs the basis for the HVAC system. However, when the user starts to modify the building the energy pattern of the building changes, thereby creating a malfunctioning HVAC system. An example was presented on the MER and SER rooms in office buildings. The user of the building adds a lot of additional ICT in these rooms, creating an additional cooling demand. One of the experts replied that the cooling itself is not a problem, unless the excess heat is put to good use in the building or in the thermal energy storage system. Excess heat should not be dumped in the outdoor environment.

Urban level
When the steps of the building level are executed, but the energy loops in the system cannot be closed effectively the possibilities on a neighbourhood level should be analysed. This 'Energy Potential mapping' should only be done on a neighbourhood or district scale. Larger areas are not feasible due to heat loss during transportation.

There are some requirements and limitations and mentioned for reusing residual energy flows during the focus group:

- The mini grid cannot be based on how the functions are currently located in order to create a sustainable network. When building functions change over time the network still needs to be functional. For example: when a supermarket moves to different location and is replaced by a shoe store, the network should still be effective. Therefore, open heat networks are needed.

- For developers it is difficult to implement these lower caloric heat networks because a developer is dependent on all the stakeholders involved. When these types of initiative are executed in practice that is often the bottleneck. When one of the stakeholders is unwilling to cooperate the reusing of residual energy flows at a neighbourhood level stopped. Municipalities cannot impose cooperation from different parties unless the municipality completely has completely mapped the energy patterns itself.
- Heating and cooling demands are easier to solve on a neighbourhood level than on a building level. However, difficulties arise with shared responsibilities and risks and which stakeholders takes the lead. This is already happening with the sharing of Thermal Energy Storage systems (TESS). Municipalities are asking developers to set up a joint TESS for their developments on two plots using one source.

For newly build buildings the supply of high caloric heat is inefficient. Newly built buildings are well isolated, therefore low caloric heat suffices. Producing higher caloric heat cost a lot more energy than with low caloric heat production. Office buildings also don't require a high caloric heat network for heating.

The reusing of residual energy topic is concluded with the following statements:
- Opportunities with cold and heat within the building are not yet optimally exploited.
- Mix use developments bring more possibilities for reusing residual energy.

<u>Storing of electrical energy</u>
There is currently being experimented with the storing of electrical energy in electric vehicles. One of the exerts Interesting total concept to connect mobility with buildings. If you envision an office and that cars will be electric in the future, you would mainly have a few still filled batteries in the start-up phase of an office that can supply power before the office itself starts producing with the panels. Can help with peak shaving.

Part 3: Renewable energy supply
The third part of the focus groups is started with the following statement by the researcher: It is impossible to develop zero energy office buildings within the BENG framework without the implementation of BIPV in the facades of the building.

One of the experts replied that ambient heat and cold should be the main source for the heat demand for office buildings. However, heat pumps and artificial lighting still run on electricity. The expert claims that solution for suppling this energy lies in very well integrated and beautiful PV on the facades. A major advantage of BIPV is the simultaneous production and demand. This resolves the overproduction in the summer when the demand for energy is low due to holidays etc. and the shortages in the winter when the demand is high. Currently, because of the costs of PV panels, they are optimally oriented to produce the maximum amount of energy per panel per year. We need to go to an optimal energy production that is equal to the energy demand. By doing this less energy needs to be stored.

<u>Allocation of electrical energy generated outside of the building plot</u>
During the day residences with PV have an over production of electricity because everyone is working in the office, this is in line with the exchanging of the new stepped strategy. However, this is not valued anymore in the BENG framework. Local mini grind can be used to exchange electricity between functions with different energy patterns. In this system electric vehicles can function as batteries. The net itself can also function as a battery, because batteries are expensive.

Peak shaving

Smart electronics that automatically stop when not necessary is needed for peak shaving. These types of Technologies are currently already applied on boats. These technologies should be applied more in buildings to reduce demand and shave energy peaks.

Currently peak shaving is a last-minute addition, and not part of the total energy system. Peak shaving demands a total installation. Should not be added during the final phases of a project. Installation can be smaller when it is taken into account from the first phases of the project. A challenge with peak shaving is that the developer not responsible for exploitation of the building. It is currently an add-on, used to reduce the electrical connection capacity. Not for aligning the peaks and valley of the energy demand.

Biomass

Combined Heating and Power (CHP) systems fuelled by biomass are not financially feasible within the built environment. That is the main reason that they currently are not implemented.

Part 4: Open comments

One expert asked what the limits and challenges are on a building level are for new developments. The expert with a background in real estate development replied that the limited surface area is the challenge for inner-city developments. PV on the roof competes with two or three other functions. Roofs are also needed for an outdoor area for the users of the building, biodiversity and water buffering. There is a limitation or challenge. For the application of PV in the façade the limits are that there is a discussion on fire safety and a discussion on aesthetics. On an aesthetic level the market is developing there are solutions which are considered aesthetically pleasing. Furthermore, the efficiency is of PV on the facades is considered very low.

During the focus group there was a general note on aspects mentioned in the energy demand section of the technical design: there is a large difference between the actual energy efficiency of office buildings and the energy demand as valued by the NTA8800 determination method. NTA8800 is a fictional or political determination method for the energy efficiency of buildings. Some aspects mentioned in the technical design do have an impact on the energy actual energy demand of office buildings but are not valued by the NTA8800.

Another expert mentioned not to focus on heat and exchanging because this is not the core problem. Not even 10% of the total energy demand is needed for heating and cooling. It begins with the demand due to limited options for supply. Heating of office buildings is not a lot anymore when the first step is performed effectively. Cooling might be a bit higher, but this can be evened out by heat pumps, although they need electricity to function.

Furthermore, the main comment was given that the Technical Design should emphasize that it always starts with saving energy at the level that you can influence well: design, programming, layout, and find an optimal balance in it. When the energy system cannot be closed on a building level there can be looked in the surrounding area. This should be the new train of thought for developing office buildings: offices in a context. This should be properly reflected in the document. The Technical Design should breath this atmosphere: it is not about developing islands, but parts of the environment. It is no longer feasible to design a building that has no connection with its surroundings. Then cities will never become CO_2 neutral.