WHEN ENERGY SAVINGS BECOME A WASTE

How the environmental- and energy performance requirements of buildings can stimulate the building industry towards sustainable design of office facades in the Netherlands

RENS NIJMAN

MSc Thesis Report
Master Civil Engineering, Building Engineering, Structural Design

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How the environmental- and energy performance requirements of buildings can stimulate the building industry towards sustainable design of office facades in the Netherlands

by

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In partial fulfilment of the requirements for the degree of
Master of Science
in Civil Engineering
at the Delft University of Technology,

10-09-2019

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PREFACE

This report is the result of my graduation project. In this thesis, research about combining the environmental performance and energy performance of buildings to stimulate sustainable design of facades is conducted. This is the last step towards fulfilling the requirements needed to obtain the title Master of Science in Building Engineering at the Faculty of Civil Engineering at the Delft University of Technology. The research was carried out at TNO in Delft, where I had an enjoyable and inspiring time during the work on my thesis.

I started studying Architecture in Delft to combine creativity and technique. After completing my bachelor in Architecture, I was happy to learn more about structural design and buildings in general. Next to design and construction, the sustainability of buildings caught my attention as I found it a fascinating and valuable branch of the building industry. The subject is innovative, challenging and has great societal relevance. Therefore, I chose to further develop knowledge in this field through this graduation work.

I would like to thank my graduation committee for their inspiration, knowledge and useful feedback during this project. Thanks to Sanne van Leeuwen for her energy, enthusiasm in our weekly talks and the extensive supervision. Also, thanks to Peter Kuindersma for sharing his passion and practical recommendations. I would like to thank Eric van den Ham for sharing knowledge about the energy performance, helpful insights and guidance through the project. Thanks to Henk Jonkers for introducing me to the environmental performance, useful comments, and brainstorms about my graduation work. Finally, I want to thank Rob Nijsse for chairing this committee and steering this project in the right direction.

Hopefully, this thesis can provide inspiration and also give practical solutions to design more sustainable buildings. Enjoy reading!

Rens Nijman,
Delft, September 2019

SUMMARY

The life cycle of a building has a tremendous impact on the environment. This is due to its energy demand, production and transportation of building materials, and its maintenance. Actually, the building industry is one of the most polluting industries that contribute to climate change. In the Netherlands alone, this sector is chargeable for 50% of the materials consumed, 40% of the total energy used and 35% of the total CO_2 emissions.

To limit the effects of climate change, the Dutch government has set several requirements for new buildings concerning energy use and emissions. The energy performance of buildings is a requirement to minimise the energy demand of buildings. The environmental performance is a requirement to reduce the environmental impact of materials used in the building. These requirements correlate negatively. Therefore, when the regulations get more strict, it will not be possible to satisfy both. Thus, the requirements will adversely affect each other.

This thesis 'When energy savings become a waste' describes research about the design of facades to increase the sustainable performance of office buildings steered by the regulations energy performance of buildings and environmental performance of buildings. It is about the conflicting demand and how to design a facade in such a way that no energy will be lost because the energy reduction is less than the energy needed for the production of an element. The main research question that is answered in this research is *'How can the Dutch building industry achieve sustainable buildings by designing according to both the energy performance and environmental performance of buildings applied on facades?'*

First of all, the relation between sustainability, energy performance-, environmental performance- and circularity of buildings is established. In this research, sustainability is defined as a goal to minimize harmful emissions to the planet. This goal can be achieved in different ways , one of which is the circular building principal. A circular approach of building aims to no longer use new resources and produce no more waste. The energy performance of buildings and the environmental performance of buildings can help steer towards sustainable buildings.

Next, the concepts of the environmental performance of buildings (MPG) and the energy performance of buildings (EPC) are introduced, and their current use in methods and tools is analysed. Several methods exist in which the energy performance and the environmental performance are combined. For this research, the 'sustainability performance of buildings' (DPG) will be used, which is an objective method combining the energy and material by converting the total CO_2 emission in the energy performance to shadow costs and by adding this to the shadow costs as calculated in the environmental performance. Therefore, the sustainability performance indicates the total emissions of the whole life cycle of a product, process or building and the total costs required to bring the environmental impacts of a product, process or building to an acceptable level. The sustainability performance of buildings is expressed in shadow costs per square meter, €/m^2.

In a one-factor-at-the-time analysis, the environmental- and energy performance of buildings is calculated in different scenarios with a varying parameter in the design of the facade. For this analysis, a reference office building was used as a study case. This is a medium-sized office building with a curtain wall facade of aluminium and triple glazing. Eight variants are examined, in particular: type of glass, insulation value and insulation material, the ratio of open and closed parts in the facade, use of PV-panels on the facade, sun shading, facade composition, orientation and changing the building process from linear to circular.

The most important results of the case study are as follows:

- In types of glazing, vacuum glazing has the best sustainability score. Also, triple glazing with a total glass thickness of 12 mm is an improvement compared to

the current thickness of 16 mm. The performance of HR++ glazing is only 1% worse than triple glazing and can, therefore, also be considered in use.

- The insulation value, as well as the insulation material, has no significant influence on the sustainability performance. The reduction in energy by adding more insulation material is almost equal to the energy needed for the production of the extra material.
- The percentage of glass in the facade has a tremendous impact on both the environmental performance and energy performance. Both the performances get worse with a higher percentage of glass. The trend in the design of office building is, however, to increase the percentage of glass.
- The use of PV panels in the facade is beneficial for the sustainability performance. The revenue is small for PV panels on the north facade, and the investment will not pay off. In the other orientations the PV panels the payback time is between 11 and 15 years. PV panels on the south facade achieve the most improvement.
- The addition of sun shading will only slightly improve the sustainability performance when no louvres are included in the design and the control system is optimal to reduce the heating and cooling demand.
- A change in the facade system and materials can significantly reduce the sustainability performance. However, this is mainly caused because no louvres are added in the other facade designs. Therefore the addition of louvres is not sustainable; neither is increasing the height of the floors. The facade with wooden cladding has the best sustainability performance.
- The orientation of the building can influence the sustainability performance without changing other parameters. For the reference building, the most optimal orientation is achieved by a rotation of 90 degrees. The windows are then orientated north and south.
- The effect of different circular scenarios is calculated and compared to the reference scenario with a service life of 50 years. The scenario considering the reference situation with a realistic service life of 20 years, has the highest score of all. In the next scenario, the percentage of reuse is increased to 60% and the service life of the facade is 20 years, resulting in an improved sustainability performance of 2%. In the last scenario, the service life is extended to 100 years, causing an improvement of 4%.

Conclusions of this research are only based on the sustainability performance and do not take into account social and financial aspects. Therefore in some variants, the most sustainable solution might not be feasible in practice. For example, vacuum glazing is very expensive, and consequently, triple glazing with a thickness of 12 mm is advised to use. One realistic variant is calculated with a combination of variants. In this scenario, financial and social feasibility are taken into account, and an improvement of 15,5% is achieved, showing the value of this integral approach.

Based on this research, it can be concluded that the Dutch building industry can achieve sustainable buildings when the design is focused on decreasing the sustainability performance of buildings. An integral approach considering both energy and material use is essential when enhancing the sustainability performance of buildings. The goal of the Dutch government to steer on CO_2 emission can help to improve the sustainability performance. However, the relationship between the sustainability performance and CO_2 emission is not entirely linear. Energy and material use need to be balanced together to accomplish a sustainable built environment.

To be able to use this knowledge in a broader context it is recommended to conduct this research for a combination of the used variants, take into account design aspects of the whole building, and perform analysis on multiple buildings. In this research, only the aspects of sustainability concerning the planet are taken into account. Aspects regarding people and profit should also be considered to determine the feasibility of sustainable measures.

NOMENCLATURE

LIST OF ABBREVIATIONS

BENG	=	Bijna Energie Neutrale Gebouwen (=nZEB)
BREEAM	=	Building Research Establishment Environmental Assessment Method
C2C	=	Crade to Cradle
CO_2	=	Carbon dioxide
CPG	=	Circulariteits Prestatie Gebouwen (Circularity Performance Buildings)
DGBC	=	Dutch Green Building Council
DPG	=	Duurzaamheids Prestatie Gebouwen (Sustainability Performance Buildings)
EPD	=	Environmental Product Declaration
EPG	=	Energie Prestatie Gebouwen (Energy Performance Buildings)
FV	=	Future Value
GFA	=	Gross Floor Area
GPR	=	Gemeentelijke Richtlijn Gebouw (Municipal Guideline Building)
IFD	=	Industrial, flexible, demountable
LCA	=	Life Cycle Analysis
MKI	=	Milieu Kosten Indicator (Environmental Costs Indicator)
MPG	=	Milieu Prestatie Gebouwen (Environmental Performance Buildings)
MRPI	=	Milieu Relevante Product Informatie (Environmental Relevant Product Information)
NIBE	=	Nederlands Instituut voor Bouwecologie en Ecologie (Dutch Institute for Buildingecology and ecology
NOM	=	Nul Op de Meter (Zero On the Meter)
NPV	=	Net Present Value
OFAT	=	One factor at a time
RVO	=	Rijksdienst voor Ondernemend Nederland
SBK	=	Stichting Bouwkwaliteit
SHGC	=	Solar Heat Gain Coefficient = g-value
PV	=	PhotoVoltaic / Present Value
nZEB	=	Nearly Zero Energy Buildings

LIST OF SYMBOLS

U	=	U-value in $W/m^2/K$
A	=	Area in m^2
$l\psi$	=	perimeter length in m
ψ	=	linear thermal transmittance in W/(mK)
λ	=	Thermal conductivity in $W/m^2/K$
L	=	Length in m / service life in years
r	=	Discount rate
R	=	Revenues / Insulation value in m^2K/W
C	=	Costs in €
n	=	Number of years
E	=	Energy
t	=	Thickness in mm
g	=	Solar Heat Gain Coefficient (SHGC)

LIST OF SUBSCRIPTS

w	=	Window
g	=	Glass
f	=	Frame
g	=	Building
p	=	Product
tot	=	Total

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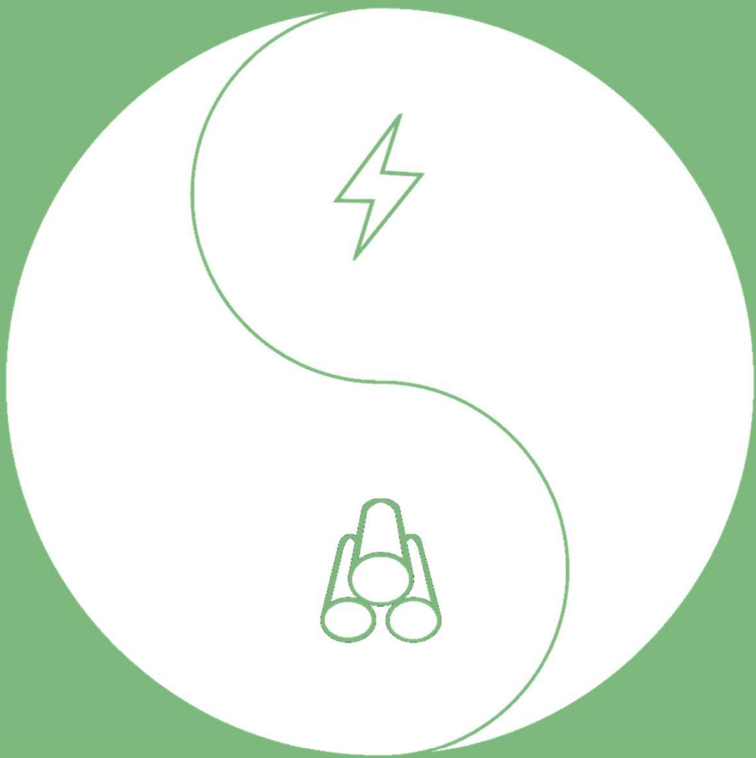
1. RESEARCH FRAMEWORK



In this chapter, an introduction is given on sustainability, the problem is stated, and the scope and objectives of the research are explained. Furthermore, the research questions are proposed, and lastly, the research methodology is illustrated.

1.1 INTRODUCTION OF SUSTAINABILITY

Climate change is an issue that will have severe consequences on the environment and to society. The rise in the average temperature on earth is an aspect of climate change known as global warming. (NASA, 2019) To limit the effects of global warming, immediate action is necessary. This can be done by implementing measures in the most polluting industries, such as the building industry. In the Netherlands, this sector is chargeable for 50% of the materials consumed, 40% of the total energy used and 30% of the total water consumption. Furthermore, 40% of the waste is from the building industry, and the sector is responsible for 35% of the CO_2 emissions, see figure 1. (Dijkstra & Kamp, 2016)

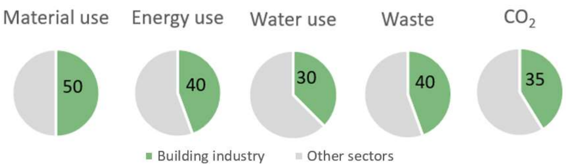


Figure 1: Consumption of the Dutch building industry

A lot of the materials and sources used for our energy consumption and buildings are not renewable. And thus, depletion of finite resources and exhaustion of materials is a genuine problem. The building sector stands in front of an enormous transition regarding the reduction of negative environmental effects. Buildings should be designed with reusable or reused materials and renewable resources so that no finite resources are needed and less waste is produced. The ambition of the Dutch government is to build entirely according to principles of the circular economy in 2050 and to realise 50% of this goal in 2030. (Transitieteam, 2018)

In the past decades, many energy-saving measures have been implemented. For example, the insulation value for windows in new buildings should be higher than achievable with single glass. (Rijksdienst voor Ondernemend Nederland, 2018) There is still a large amount of energy needed to heat and cool the building but also for hot tap water and other installations. Methods to produce energy sustainably without using finite resources already exist. Examples are wind energy, solar energy, and geothermal energy. Often these methods are costly and less efficient than conventional ways and are therefore not implemented on a large scale yet. The energy performance is regulated in the Dutch building degree and is still under development. Currently, the requirement for energy performance coefficient (EPC) of office buildings is the dimensionless number 0.8, further elaborated in chapter 2.3. (Rijksdienst voor Ondernemend Nederland, 2018)

Since 2012 it is obligatory in the Netherlands to perform an environmental performance for all new residential and office buildings with a gross floor area larger than 100 m^2. (Rijksoverheid, Wetten en regels gebouwen, 2018) From January 2018 on, the environmental performance of buildings, (MPG=milieu prestatie gebouwen) which is expressed in €/ m^2, should be less than 1,0. The MPG can be calculated with the Life Cycle Assessment (LCA) methodology. In this methodology, 11 impact categories are considered, each addressing a specific environmental aspect. This required value of 1,0 is already attained by most existing buildings, see figure 3. However, this requirement is only a start and is expected to get more strict in the coming years.

To achieve a sustainable building industry, the regulations can be adjusted and used to stimulate the use of reusable, renewable materials. Therefore, a method should be available to evaluate the sustainability of buildings, used measurements and materials.

This research looks on to what extent sustainability can be achieved with the environmental performance and energy performance.

1.2 PROBLEM ANALYSIS

The regulations for environmental and energy performance of buildings are expected to be tightened in the coming years. (Rijksoverheid, Wetten en regels gebouwen, 2018) These parameters correlate negatively, see figure 2. Data on research about the relation between MPG and EPC of residential buildings are used. In this figure, the energy performance on the horizontal axis is plotted against the environmental performance on the vertical axis.

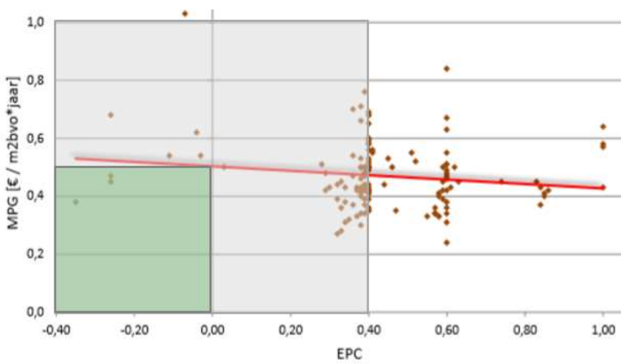


Figure 2: Relation environmental and energy performance Based on (Nieman & Anink, 2017)

The light-grey area represents the current requirements of EPC and MPG for residential buildings (EPC=0,4 or lower and MPG=1,0 or lower) The dark-grey area represents requirements that the current buildings wouldn't be able to fulfil. (EPC = 0,0 or lower and MPG = 0,5 or lower). In this figure, a large share of the buildings does not even meet the current standards. The MPG requirement is easily fulfilled by most buildings; this is also visible in figure 3. In this figure, the environmental performance of offices and residential buildings is plotted. For offices, only 5% of the buildings have an environmental performance of 0,9 or higher and in the residential sector 5% score above 0,68. A large difference in environmental performances between offices and residential buildings is found. Therefore, it is important to make a distinction in building types in this research.

When the regulations become more strict in the coming years, the negative correlation could cause problems in fulfilling both requirements. For example, to improve the energy performance, insulation is added to the building. This insulation causes an increase in environmental performance, although this performance also needed to be improved. Because of the strict energy performance requirements, the tendency is to add more material to a building, for example, extra layers of glass, insulation or Photovoltaic (PV) cells. This extra material has a negative impact on the environmental performance. Therefore, it is even harder to lower the environmental impact and satisfy the requirements. To anticipate this conflict, the environmental performance and energy performance cannot be seen apart from each other. To achieve sustainable buildings and to meet both requirements, these parameters should be integrated and optimised together.

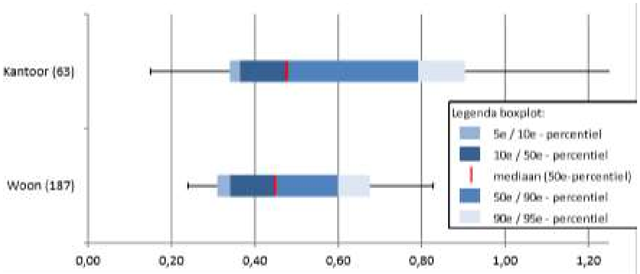


Figure 3: Distribution of environmental performances for residential buildings and offices (Nieman & Anink, 2017)

1.3 SCOPE

Sustainability is a very complex terminology and includes many aspects. Therefore, it is important to limit the scope and clearly state what aspects of sustainability are taken into account. According to John Elkington, the pillars of sustainability are people, planet and profit. (The Economist, 2019) In figure 4, components of sustainability are shown. The pillar 'people' is subdivided to quality of use and health and comfort. Energy and materials represent the pillar planet, and future value stands for profit. The focus of this research will be on materials and energy, the planet part of sustainability, as can be seen in figure 5. The planet and profit parts of sustainability are left out of scope in this study. This choice is further elaborated in chapter two.

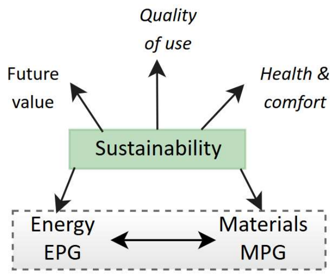


Figure 4: Components of sustainability

This research will be limited to office buildings as the type of building has a lot of influence on material and energy. Less research is done on offices than residential buildings. In the Netherlands, currently 6 million m² of the office area is not used while there is a great demand for residential buildings. (Geraedts & Voordt, 2015) To zoom in the design of the facade will be looked at in more detail.

Health and comfort, user quality and profitability can be seen as boundary conditions in this research.

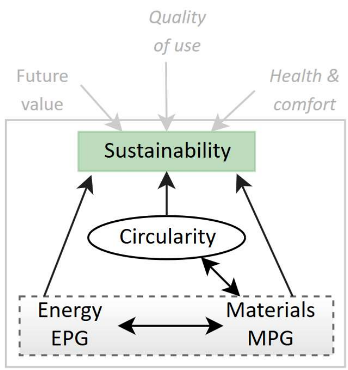


Figure 5: Scope of research

1.4 OBJECTIVES

In this research, the following objectives are formulated:

- Define the terms sustainability, circularity, environmental performance and energy performance and the relation between these terms.
- Define a way to combine both parameters to obtain more sustainable buildings and to be able to know when energy is wasted, based on existing tools to combine the environmental performance and energy performance.
- Analyse relevant design parameters that influence the energy- and environmental performance of buildings.
- Describe the relevance of the case study in facades.

- Analyse different facade concepts on energy- and environmental performance.
- Get to know the influence of different design parameters and optimal values in each variant.
- Recommend improved requirements for the Dutch government to steer towards more sustainable buildings.

1.5 RESEARCH QUESTIONS

The main research question of this research reads:

‘How can the Dutch building industry achieve sustainable buildings by designing according to both the energy performance and environmental performance of buildings applied on facades?’

To answer this question, the following sub-questions are formulated:

1. What are the relations between sustainability, energy performance-, environmental performance- and the circularity of buildings?

In this sub-question, the terms sustainability, circularity, environmental performance and energy performance are defined, and the relations between these terms are examined.

2. How are the environmental performance and energy performance currently combined in methods and tools to indicate sustainability, and how should these parameters be combined to indicate sustainability?

In the second sub-question, existing tools and methods for combining environmental performance and energy performance are evaluated. A way to combine and weigh both parameters is suggested to obtain more sustainable buildings.

3. How should the design of office building facades be approached in the Netherlands when implementing optimised environmental performance and energy performance requirements?

In the last sub-question, different approaches to design facades will be analysed regarding environmental performance and energy performance. With the outcome of this study, a design of optimal sustainable facade in terms of environmental and energy performance can be made.

1.6 METHODOLOGY

The research can be subdivided into four phases. This is visualised in figure 6. In the first phase of the research, the problem and scope are defined. Then the terms sustainability, circularity, environmental performance of building and energy performance of buildings will be explained through a literature study. Also, the relations between those terms will be established.

To define a way to combine the EPG and MPG existing tools and methods are analysed and discussed. The relevant design parameters that are of influence for EPG and MPG are defined in the synthesis phase. This will be done by analysing research results of variations in design.

In the implementation phase, the relevance of facades in this subject is shown by a literature review. Then the EPG, MPG, and total energy use are analysed of different scenarios of facade designs. These scenarios are further explained in table 6 in chapter 4.

In the optimisation phase, the results of the case study will be analysed, and the sensitivity of parameters will be evaluated. Then the optimal design parameters can be established by means a discussion of the results in combination with essential assumptions made and limitations of research.

After the discussion, conclusions and recommendations for future research can be formulated.

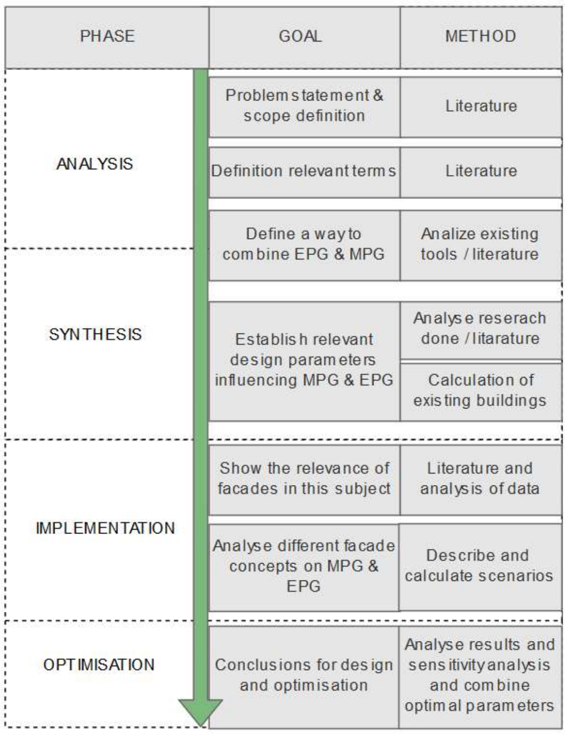


Figure 6: Methodology

2. SUSTAINABLE BUILDING DEFINITIONS

In this chapter, the terms sustainability and circularity will be defined in the context of this research. Then, the background of the energy performance and environmental performance of buildings will be elaborated. At last, the relationship of these terms with sustainability is explained.

2.1 SUSTAINABILITY

2.1.1 Definition

Sustainability is defined in the dictionary as 'The ability to be maintained at a certain rate or level.' (2019) It is crucial to develop buildings in a sustainable way to maintain their value. The social value, environmental value, and economic value are essential to sustain the building. The triple bottom line is a framework to drive decision making first used by John Elkington in 1994, including the three pillars people planet and profit. (The Economist, 2019) Nowadays, these three pillars are often seen as the three aspects of sustainability, see figure 7.

Social, economic and environmental aspects should be considered in an integral approach. This causes sustainability to be an enormous broadly used and increasingly complex concept applicable and relevant in various themes, products and branches. It is particularly complex due to the lack of a clear definition of the phenomena and existence of various ideas, visions and approaches. The concept of sustainability depends on the perspective of a company or person. (VMRG, 2018)

Figure 7: PPP (Duurzaam beleggen, de basis, 2019)

Sustainable development is, according to the widely known and accepted definition of the Brundtland commission, 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' (Brundtland, 1987) This means that we have the responsibility to take care of the planet and reduce harmful emissions. Until now, the profit of companies mostly is the driving force in decision making. To make sustainable development feasible, the mechanism of demand and supply has to change.

In an integral approach where the three 'P's cannot be seen apart from each other, it is complicated to measure sustainability. Because there are so many aspects that matter, it is not easy to compare and to weigh the different aspects of sustainability. Sustainability can be seen from a lot of different perspectives, and therefore, a 'sustainable building' can mean a scale of different things. Several organisations and companies have other objectives and perspectives and will give a different priority to aspects of sustainability. Therefore it is important first to establish the boundaries and scope and what priority is given when considering sustainability.

From the problem statement, it became clear that the requirements of the Dutch government focussed on reducing emissions to the environment are decisive to design sustainable buildings. Therefore the priority is given to environmental aspects in this research. The requirements of the Dutch government are derived from the Paris agreement, an agreement of the United Nations, including a plan to limit the rise in temperature with 1.5°C. (United Nations, 2019) Sustainability in this thesis will be understood as minimalization of harmful emissions to the environment. Also, minimal finite resources should be used as possible to produce energy and materials to build. Note that other components of sustainability are still relevant and are seen as boundary conditions in this research. Without considering aspects concerning people and profit, it is not possible to make a design that can be implemented. Including social aspects and profitability as boundary conditions, the research will remain realistic.

2.1.2 Sustainable building discussion

In the Dutch building industry, a building is generally called sustainable once a sustainability label or certificate is awarded. This raises a number of questions about the actual value of a sustainability label or certificate. In chapter 3, several tools that indicate sustainable buildings will be analysed. (VMRG, 2018) For example, according to GPR-Gebouw, sustainability has five different topics, namely materials, energy, future value, quality of use, and health and comfort. (GPR gebouw, 2018)

Despite the fact that many organizations and countries in the world are actively involved in the sustainability issue, there is no clear strategy to design sustainable buildings and no clear definition of sustainable buildings. The Dutch government is developing more regulations aimed at creating sustainability in the built environment. For example, the Netherlands is participating in the climate agreements of Paris. This climate agreement states that there should be 49% less harmful emissions in the Netherlands in 2030 in comparison to 1990 to counteract climate change. This is 48,7 megaton (48,7*10^9 kg) of CO_2 less. (Rijksoverheid, Over het klimaatakkoord, 2019)

The ambition of the Dutch government to accomplish a circular economy in 2050 is written in an agreement to use sustainable resources for products and buildings, the 'Grondstoffenakkoord'. Already a lot of parties like companies, governments, societal organisations and knowledge institutions are participating in this agreement. (Rijksoverheid, 2019) The ambition of this agreement is to reduce the use of primary resources with 50% in 2030 in comparison to 2014. (Dijkstra & Kamp, 2016) This implies that the current building standards have to change significantly. 'We cannot just add sustainable development to our current list of things to do but must learn to integrate the concepts into everything that we do.' (The dorset education for sustainability network, 2019)

Adjacent to these agreements, two important requirements are set in the National building degree to stimulate the building industry towards sustainable practices. The energy performance of buildings is a way to measure the CO_2 emissions of the building-related energy used, further elaborated in 2.3. The environmental performance of buildings is a way to measure the environmental impact of materials used in a building, explained in more detail in 2.4.

The prediction of the level of sustainability is uncertain. This is because it is hard to predict the future. It can be sustainable to design a building for 100 years, but if the demand is entirely different in 20 years, the service life of 100 years will not be reached. Also, when designing a building completely demountable, there is a risk of adding too much material and quality because the elements might not be reused in the future. One of the most challenging problems in sustainable development is the time frame. Society can be developed for 10 years, a whole lifetime or even a thousand years. (Worster, 1993) The longer the service life of buildings, the less certainty of design assumptions can be assured.

Sustainable design can be defined as design which seeks to minimise negative environmental impacts over the whole life-cycle of the project. There are several strategies to design sustainable buildings. The most known and used strategy is the Trias Ecologica: (Ministerie van VROM, 2010)

1. Reduce the demand
2. Use sustainable resources
3. Use finite resources efficiently.

Other strategies to achieve sustainable building are:

IFD-Building: Industrial, flexible and demountable building is an approach to design, develop and to build a building. With this method, the possibility arises to adjust the building to a changing demand during the service life. build for the future.

Cradle to Cradle (C2C) is based on the principle 'waste is food'. The three basic rules of C2C are: waste is food, the sun is the energy source and respect the diversity. C2C is following the same principle as a circular economy (see 2.2). (Ministerie van VROM, 2010)

2.2 CIRCULARITY

2.2.1 Circular building process

Circularity is an often-used term when considering sustainability. Circular building is an approach of building that corresponds to the line of a circular economy. In a perfect circular economy, no more resources (input) are necessary, and no more waste (output) is produced, see figure 8.

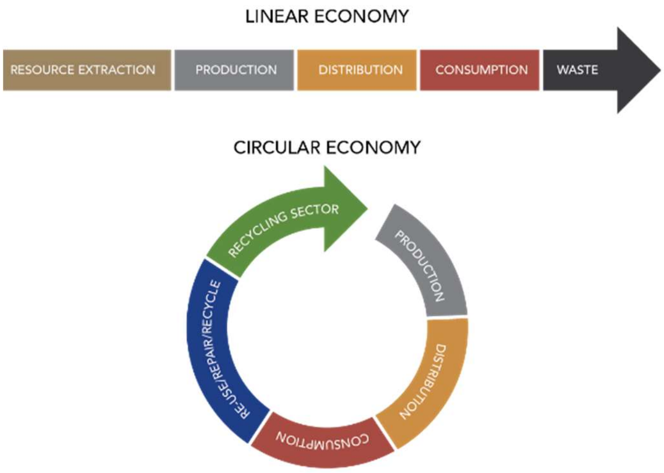


Figure 8: Linear and circular economy (Bradley, 2018)

In the traditional linear building process, the following stages can be distinguished:

1. Excavation of resources
2. Production of (half)products from raw materials
3. Distribution of products and assembly of a functional product of construction
4. Consumption of the product is the use phase where several maintenance and repair actions may be required
5. Demolishing at end life phase
6. Landfilling

In a circular process, the excavation of raw materials and the landfilling phase are substituted by reuse and recycling of the materials or products. Because of the relatively long service life of buildings, the speed of innovation in the building industry is slow. Because of a lack of experience regarding reuse of elements, financial risks of investing in the circular processes exist. Responsibility, uncertain investments and corresponding risks are blocking action for most companies.

Circularity is thus focussed on reuse and recycle of materials. It is not just a business model. A circular economy asks for system thinking. People and businesses are part of a system where the actions of one actor influence other actors. (Ellen Macarthur Foundation, 2013) Making the building process circular is a way to achieve sustainable building. Sustainability and circularity have respectively a goals-means relationship.

2.2.2 Strategies circular building

There are several strategies to achieve a circular building process. It is unambiguous that circular building not simply implies buying circular products. A different way of thinking is needed, described as a paradigm change by Brown. This means that a fundamental assumption changes in a short period of time. We have to start seeing the economy as part of the ecological system, instead of the other way around. (Brown, 2000)

Natural ecosystems have many similarities with an ideal circular economy and serve as an example in the arrangement of a circular economy. In ecosystems, use of resources and waste are minimized. Using this as an example, thinking about the building industry as a complete system is useful. To be able to make the transition to a circular economy the following aspects in the design process must be taken into account: minimize material use, design demountable and adaptive, increase the service life of materials, high-quality recycle and use renewable materials. (Levels-Vermeer & Oorschot-Slaat, 2016) This corresponds to the strategy of Lansink.

Ladder van Lansink

In the ladder of Lansink, a hierarchy is given of environmental friendly methods to process waste. The higher on the ladder, the more circular and sustainable, see figure 9. In every step, strategies can be thought of to fulfil this step. The steps are:

1. Reduce: Prevent waste and reduce the number of materials used.
2. Re-use: Use the product again for the same goal.
3. Recycling: Extract resources from old products.
4. Energy: Burn materials and gain energy.
5. Incineration: Burn materials without energy recuperation.
6. Landfill: The least desirable option and fits in the concept of a linear building process.

Figure 9: Lansink's ladder (Recycling.com, 2019)

The theory of Lansink is one strategy to achieve a circular economy. Within these steps, several methods can be thought of, representing their own strategy to achieve a circular building process. Below, different examples are shortly explained.

10 R's

The 10-R model is a detailed version of the Ladder of Lansink. 10 elements starting with an 'R' describe the level of circularity of a product or material. This is used by a lot of companies as an ingredient for a new method and relevant strategies. It consists of the following elements: (from a circular to linear perspective) (Koolen, 2019)

10. Refuse: To prevent the use of materials
9. Reduce: To diminish the use of materials
8. Rethink: To (re)design a product towards circularity
7. Re-use: To find new product use
6. Repair: Maintain and repair the product to increase the service life.
5. Refurbish: Improve the quality of a product
4. Remanufacture: Produce a new product of second-hand materials
3. Repurpose: Re-use the product in another function
2. Recycle: Recover materials to make them suitable for reuse. A distinction is made between downcycling and upcycling. In downcycling, the materials are processed into new materials of less quality and reduced functionality. In upcycling, the materials are processed into materials with the same or higher quality and better functionality.
1. Recover: Extract energy from materials.

Ownership

In a circular economy, the design of buildings is focussed on closing the cycle and restore and reuse materials and products. Therefore, for technical products, the circular economy could replace the concept of a consumer with that of a user. In a circular economy, a strategy can be to lease, rent, or share sustainable products. This can also be applied to facades. The ownership of the facade(element) changes and the focus lies on value preservation. (Ploeger, Prins, Straub, & Brink, 2017)

Urban mining

The urban mining collective is an innovative company to re-use or repurpose materials from demolition projects. (Urban mining collective, 2019)

Increase material productivity

The Ellen MacArthur foundation made a clear illustration of the circular economy, see figure 10. It shows how technical and biological-based materials cycle through the economic system, each with their own set of characteristics. In the building industry, technical nutrients are used, so the right side of the model is relevant. In different circles, the elements of the Ladder of Lansink can be recognized. To increase the material productivity, four principles can be distinguished:

1. Power of the inner circle

The smaller the circle, the less a product has to be changed and the more savings of material, labour, energy and capital.

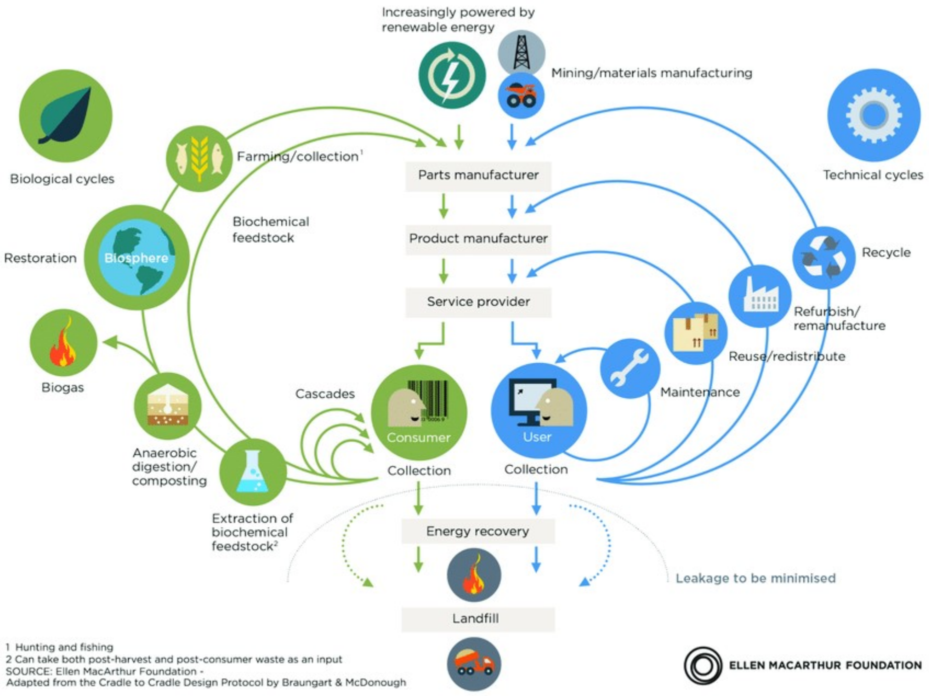


Figure 10: Model circular economy Ellen MacArthur (Ellen Macarthur Foundation, 2013)

2. Power of circling longer
The longer the circle, the more the number of cycles is maximised.
3. Power of cascaded use
The more diverse reuse across the material value chain, the more virgin materials it can substitute.
4. Power of pure circles
The more uncontaminated materials are used, the more quality and efficiency is kept in the cycle.

These four principles offer opportunities to create and maintain value in comparison with linear principles and material use, see figure 11. (Ellen Macarthur Foundation, 2013)

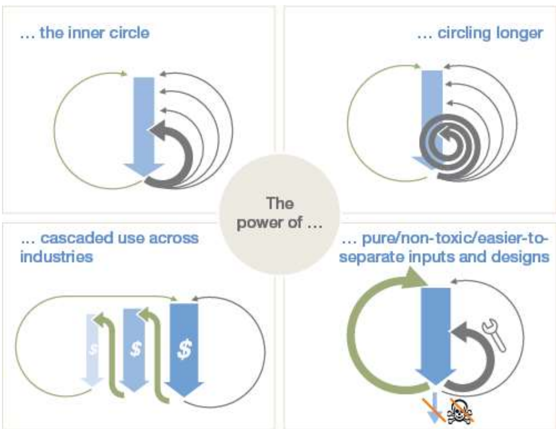


Figure 11: Principles to increase material productivity (Ellen Macarthur Foundation, 2013)

A circular economy has a large potential to realize a more sustainable world from an ecological view. Also, on a social level, it can be of importance because in a circular economy threats of climate change will decrease, and therefore, it leads to a more liveable world. Nevertheless, a focus on the material side of sustainability can be a possible danger because it may give less attention to the social side. (SMO promovendi, 2016)

Challenge circular building

Learning for the circular neighbourhood Buiksloterham, the challenges appeared to be limited physical space and sometimes conflicting interests of the residents and owners. Also, the infrastructure has to cope with the ideas of the circular building process. For example, the existence of a district heating network in the surroundings interferes with the implementation of a more sustainable heating system. (SMO promovendi, 2016)

In general, it is difficult that it is not yet clear on which scale (local, regional or even larger) circular initiative can best be implemented. (SMO promovendi, 2016)

2.3 ENERGY PERFORMANCE OF BUILDINGS

2.3.2 Energy Performance Coefficient (EPC)

Since 1995, the Netherlands is familiar with minimum energy performance requirements for new buildings. (Rijksdienst voor Ondernemend Nederland, 2018) The Dutch Building Decree sets requirements for the energy efficiency of new buildings. The standard for energy efficiency is called the Energy Performance Coefficient (EPC). The conditions of the EPC are written in the norm 'NEN 7120 Energieprestatie van gebouwen (EPG)'. This standard applies to new residential and non-residential buildings. (Rijksdienst voor Ondernemend Nederland, 2018) During the past decades, the requirements have become more and more strict. In the beginning, the energy performance was expressed in MJ/ m^2. This requirement was only about building-related energy. As a consequence, the energy bills appeared to be higher than expected when costs for domestic energy were included. This was confusing, and the Dutch government decided to divide the energy performance by a certain number. Since then, the EPC is a number without dimension and has become more and more complicated by adding several correction factors to be able to measure different building types in the same method. (Loos & Gaalen, 2019)

After several years the dimensionless number was not clear enough anymore to be the criteria for energy performance of buildings. Therefore the EPC will be dilapidated by the introduction of the Zero-Energy Buildings requirements (nZEB) in 2020. (Groot, 2019) The EPC is calculated based on building properties, installations and materials used. Several software programmes are known to calculate the EPC value. The EPC requirement for offices is currently 0,8, for residential buildings, it is more strict, namely 0,4.

2.3.2 Nearly zero energy buildings (nZEB, BENG in Dutch)

From 1 July 2020 on new buildings, both residential and non-residential, must comply with the requirements for nearly zero energy-neutral buildings (nZEB). (Rijksdienst voor Ondernemend Nederland, 2019) nZEB is the result of the Energy Agreement for sustainable growth and the European guideline EPBD. (European Commission, 2019)

The energy performance for nearly zero-energy utility buildings is determined based on the following three criteria:

1: A maximum energy demand of 90 (revised value of 2018, before it was 50) kWh/ m^2/year. To calculate this, the total energy need for cooling and heating is summed.

2: A maximum primary fossil energy use of 40 (revised value of 2019, before it was 25) kWh/ m^2/year. This is a sum of the primary energy used for heating, cooling, hot tap water and ventilation. For utility buildings also the lighting and humidification are taken into account. When renewable energy resources are available, the primary energy is reduced by the amount of renewable energy induced.

3: A minimal share of 30% (revised value of 2018, before it was 50%) renewable energy used. This is calculated by dividing the share of renewable energy by the share of primary fossil fuels energy use.

The nZEB requirements were first proposed in 2015 and revised in November 2018 and June 2019. The new requirements of 2018 caused a lot of indignancy in the building industry. It seems like a step back regarding the level of sustainability. Professionals claim that the new performance is even worse than the average EPC-building at the moment, see figure 12. (Ensoc, 2019) For utility buildings, the EPC only changed in 2000 and 2003. In 2006 the requirement was 1,5, in 2013 it was 1,1, and in 2015 it changed to the current requirement of 0,8.

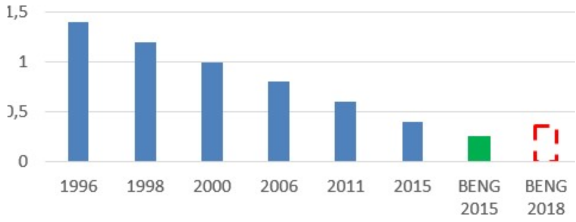


Figure 12: Development EPC (DWA, 2018)

It is hard to say that the new requirement is a step back because the requirement has completely changed and is now consisting of three different elements; therefore, it is like comparing apples to oranges. The second nZEB requirement can mainly be compared to the old EPC requirement, but the first and third requirements are new, and therefore, the requirements could be not as easily fulfilled as thought.

The requirements published in 2018 are fundamentally different from the requirements of 2015. The assessment method changed, and therefore, the requirements are nearly incomparable. An important difference is the ventilation system taken into account in the first nZEB requirement. In the new method, a standard ventilation system (C1 system) is chosen. So the used ventilation system is not relevant for the first nZEB requirement results anymore. As a consequence, in the calculation, the Rc values will decrease, and it will have less effect to include thick insulation because, with the standard ventilation system, a lot of air infiltrates the building. The relationship between the second requirement of nZEB and EPC is large but not linear, see figure 13. This is because the energy consumptions calculated are not similar. For example, in the nZEB calculation, lighting is not included, contrary to the EPC calculation. (Kruithof & Valk, 2016) In figure 13, the EPC and nZEB 2 are plotted for different projects. Note that the steepness of the line has no meaning. Results of another research are analysed. In figure 14, the EPC and nZEB 2 of different sustainable measures are plotted of four different residential building types. The type of building has a large influence on the EPC and nZEB values. The curve of both criteria is comparable but not the same.

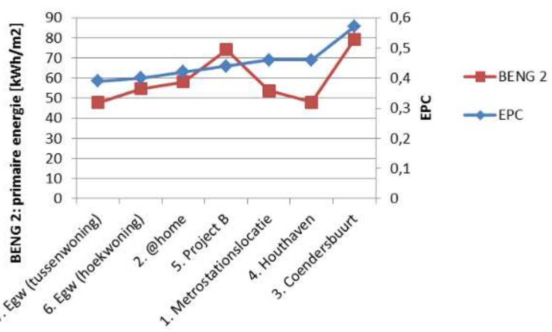


Figure 13: Relation EPC/ nZEB 2 (Kruithof & Valk, 2016)

The requirements are changed because of the following three reasons:

- The EPC is calculated with the new norm NTA8800, which is more realistic. The old EPC calculations suggested a more favourable energy consumption than possible in practice. Therefore the energy consumption determined with the NTA8800 will turn out higher compared to the old system.
- nZEB definitions have been changed in the building sector by the Dutch government. From several comments and studies, it became clear the ambitions would be unreachable for several building types. Therefore a correction is made for buildings with an unfavourable ratio of users area and loss area.
- The estimated values in 2015 appeared to be too expensive to fulfil. An optimization has been looked for between the rising construction costs and stricter requirements. (Valk, Bang voor BENG, 2018)

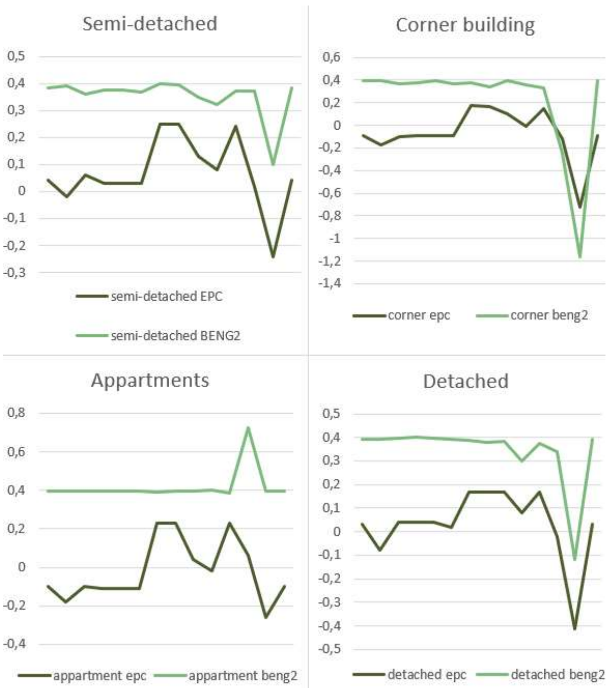


Figure 14: Relation EPC and nZEB 2 for different types of houses. The purpose of this figure is to show the relation; the measures are not important in this case. Based on (Themagroep MPG ZEN platform, 2017)

The policy for nearly zero energy buildings is still under development. After the summer of 2019, the final requirements will be published. In June 2019, a letter with the final requirements is sent to the Dutch House of representatives. (Ollongren, 2019) Calculations in this research made with software packages are, therefore based on current norms and requirements.

A few terms are often confused with nZEB. Zero- on the meter (NOM = nul op de meter in Dutch) is not the same as nZEB (BENG = Bijna Energie Neutrale Gebouwen, in Dutch). nZEB is calculated with building-related energy use. In the calculation for zero on the meter, also the domestic energy such as computers or refrigerators are taken into account. The primary fossil energy use of the nZEB buildings has to be negative to reach the level of zero on the meter.

In this research, especially the first nZEB requirement will be interesting because this is only about the energy demand. This requirement cannot be compensated by, for example, solar energy. With the new requirements, the importance of design increases. The shape and orientation have a direct relation with the energy demand of the building. (Valk & Haytink, BENG: Wettelijke eis voor energieneutraal bouwen, 2017)

In a study of Nieman about nZEB indicators of existing energy-efficient buildings, the first nZEB requirement is not met for the majority of the projects. Point of attention to be able to meet the nZEB requirements is, therefore, a further limitation of the energy demand of buildings. Within the current requirements, the energy demand is not highlighted, as the outcome of EPC calculation does not provide specific information about this. On the contrary, in the passive building approach, the focus is on limiting the heating demand and prevention of overheating. Therefore, passive building projects score well in this indicator. (Kruithof A. , 2016)

To satisfy the nZEB requirement, the energy extracted from the surroundings can only be included in the energy performance calculation of a building when a physical connection with the building exists. A study done by Arcadis and DGMR shows that increasing the insulation values no longer has a positive impact on the costs over the whole life cycle. The current requirements are optimal in term of costs. This means that it will be more expensive to insulate more. (Nieuwe BENG-eisen bekend gemaakt, 2019)

2.3.3 Influencing design parameters

In general, to improve the energy performance, the following parameters influence the energy performance: design of the building, technical execution, building installations and methods to generate sustainable energy. (DGMR, 2017)

In the design, the combination of orientation and percentage of glass in the facade is essential. Also, solar blinds and compactness are relevant. In the technical execution, the insulation values of floors, facade, roof and glass have influence. The installations used for heating, cooling, hot water, ventilation and lighting determine the energy performance of the building. These are less relevant than the design when considering the facade of the building. Also, the renewable energy source is mostly not related to the facade in existing concepts, except when solar panels are used on the facade. (DGMR, 2017)

Research has been done about innovative solutions and concepts to fulfil the requirements for almost energy-neutral buildings. These innovative techniques can help to meet the demands:

- Four-layers glazing, heat pumps with high efficiency and integration of PV-panels.
- LED lighting decreases energy consumption in non-residential buildings.
- Booster heat pumps can result in a better energy performance in residential buildings.

In the case of hospitals, more research is necessary to be able to fulfil the BENG requirements. (Heide, Vreeman, & Haytink, 2019)

In a study conducted by Nieman, the consequences of the nZEB requirements on stacked housing are indicated. Five projects are analysed having an EPC between 0,0 and 0,38. Three of the projects already fulfil the second and third requirement of nZEB whether none of the projects fulfils the requirement of energy demand. This requirement seems to be the biggest challenge. Design aspects that have significant influence regarding this requirement are the geometry, orientation, thermic shell and ventilation system. Results of the research demonstrate that compactness is favourable to decrease the energy demand. Transparency is not necessarily favourable or unfavourable; it depends on cooling- and heating requirements and differs per project. In this study, it is stated that an energy-efficient design is a boundary condition. In addition, several measures are necessary to fulfil the first nZEB requirement, such as triple glass, optimised connections, increased thermal resistance and optimised ventilation system and solar gains. (Kruithof & Valk, 2016)

The percentage of open parts and the relation of shell/users area are related to the nZEB criteria 1, see figure 15 and 16. A correlation is visible, but also other aspects determine the first nZEB requirement. Therefore the correlation is not linear. (Kruithof & Valk, 2016)

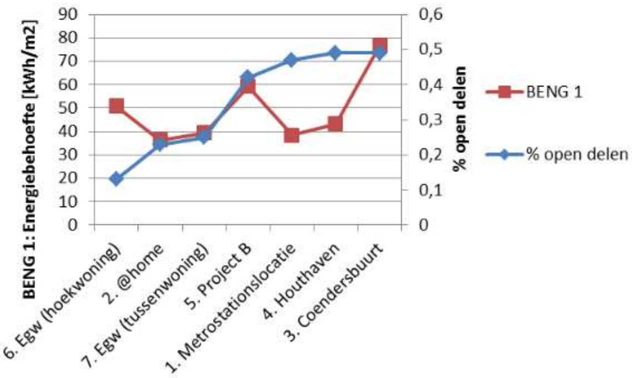


Figure 15: % open part and nZEB1 (Kruithof & Valk, 2016)

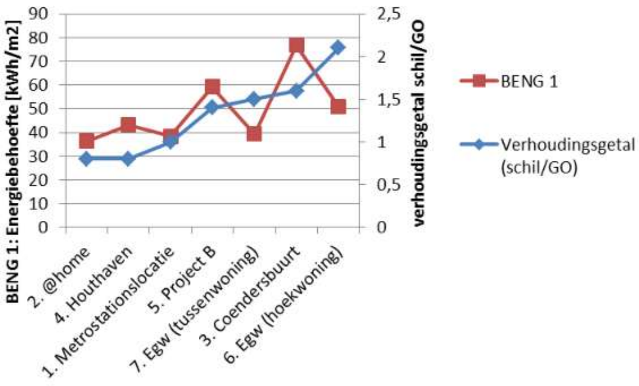


Figure 16: Relation ratio shell/floor area and nZEB1 (Kruithof & Valk, 2016)

2.3.4 Embodied energy

The energy considered in the energy performance is energy only used by installations to heat, cool, ventilate etc. The embodied energy is the energy used for mining, processing of resources, manufacturing and transport and is not taken into account in the energy performance but in the environmental performance of buildings, see paragraph 2.4.

Embodied energy can be seen as the energy locked in a material. The operation and disposal are not included in the embodied energy, but they are included in the life cycle analysis, as explained in 2.4.2. The operational energy is the energy used in operating the building over its life. (Milne, 2013) By improving the energy performance of buildings generally embodied energy is added to the building as there is used more material to insulate the building. The service life of products is essential to estimate when too much embodied energy is added. Then the reduced operational energy over the service life is less than the added embodied energy, see figure 17. By reuse of building materials, about 95% of the embodied energy can be saved. (Milne, 2013)

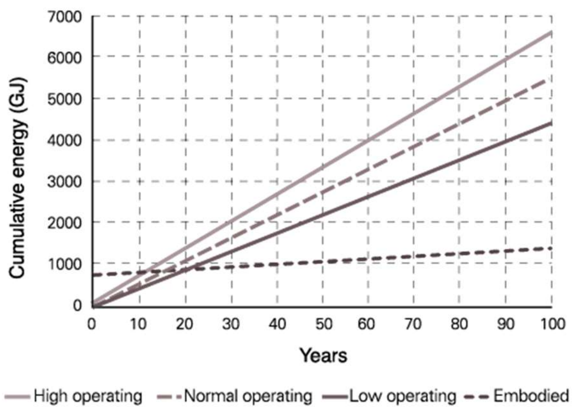


Figure 17: Operating energy and embodied energy over the years (Milne, 2013)

The energy performance requirement is a way to decrease CO_2 emissions to the environment and therefore, beneficial for the sustainability of buildings. However, the operational energy and embodied energy should be balanced so that no energy is wasted. With the new nZEB requirements the environmental performance increases on average with €0,25/ m^2, an increase of about 45%. This is mainly due to the extra installations with a service life shorter than the structural elements in the building. (Grefelman & Weerd, 2014)

2.4 ENVIRONMENTAL PERFORMANCE BUILDINGS

2.4.1 Introduction MPG

The environmental performance of buildings (MPG) indicates the environmental impact of materials used in the building. Since 2012 it is obligatory in the Netherlands to perform a calculation of the environmental performance for all buildings with a gross floor area larger than 100 m^2. (Rijksdienst voor Ondernemend Nederland, 2018) Building materials used in new buildings must not superfluously burden the environment. Therefore, a method is developed for professionals to measure the environmental performance of buildings. This method is focused on the environmental performance, which is an important indicator of sustainability. From January 2018 the environmental performance of buildings should be less than 1,0 €/m^2. The MPG can be calculated with the Life Cycle Assessment (LCA) methodology. In this methodology, 11 impact categories are considered, each addressing a specific environmental aspect. These 11 indicators can be converted into shadow costs and summed to know the shadow costs of the building or per unit of a product (per kg, m^2 or m^3). It is not necessary to perform a new LCA of the same product over and over again.

The MPG of a whole building is the sum of all shadow costs of the applied materials. Therefore it is crucial to know the technical service life of the different materials or parts of a building. Also, the materials used for maintenance will be taken into account. The total sum of environmental impacts is divided by the lifetime and the gross floor area (GFA) of the building. Therefore the MPG is expressed in shadow costs per square metre GFA per year (€/m^{2}GFA/year).

The calculation rules to determine the MPG are defined in EN15978. A detailed calculation will relatively take much time, and therefore, a lot of software tools are developed to calculate the MPG and to make it broadly accessible. To provide a clear and useable method to calculate the environmental performance of constructions over their entire service life 'Stichting Bouwkwaliteit' (SKB) has written a document about the assessment method 'Assessment Method Environmental Performance Construction and Civil Engineering Works. This method is based on NEN-EN 15804:2012 + Amendment A1 (2013), which is developed for Environmental Product Declarations (EPDs). (SBK, 2014) The assessment method is performance-oriented, not solution-oriented.

In the Netherlands, environmental data of materials, products and processes are provided by the 'Nationale MilieuDatabase (NMD)'. This database is managed by 'Stichting Bouwkwaliteit'. A producer or supplier has the responsibility to ensure a product is included in the NMD. Unfortunately, this is quite expensive, and not a lot of producers are contributing to this database yet. (Leeuwen, 2019) In the National Environment Database, three product information categories exist. (SBK, 2014)

Category 1 contains brand data, verified by an independent, qualified third party according to the SBK Verification Protocol.

Category 2 contains generic data which is verified by an independent third party according to the SBK Verification Protocol. A declaration of the representative is also included. The representative can be, for instance, be an association of producers or the Dutch market.

Category 3 also contains generic data (brand-less), but not verified according to the SBK Verification Protocol. With unverified data, the environmental profiles can be too low, or specific environmental impacts are missed. Therefore, when a product of category 3 is used a multiplication factor of 30% applies to the environmental profiles.

The new NMD of June 2017 results in an average of 40% higher environmental performance values. This is an implicit tightening of the environmental performance requirements because these requirements are based on NMD 1.0. Because of this, a correction factor of 0.4 may be used when calculating the MPG using NMD 2.0. So the environmental impact may be decreased temporarily with 0.4 so that the limiting value of 1.0 easily can be achieved. (SBK, 2014)

The required value of 1,0 €/m^2 is just a start and already fulfilled by most existing buildings. The requirement is therefore expected to be tightened in the coming years. (Themagroep Circulair Bouwen, 2018) This requirement will develop faster than the requirement for EPC. (Nieman & Anink, 2017)

The MPG requirement is active for buildings that fulfil the EPC requirement from the Building Degree. For zero on the meter- and very energy-efficient buildings, the EPC is significantly lower than the requirement. In this situation, the energy-saving measures taken can be partly left out of consideration when calculating the MPG. For example, a building is provided with 20 PV panels attaining an EPC of -0,36. To achieve an EPC of 0,4, only four PV panels are required. Therefore only four PV-panels have to be included in the MPG calculation. (Themagroep MPG ZEN platform, 2017)

Research showed that the MPG of office buildings, with a GFA lower than 5000 m^2, varies from 0,6 till 1,1. The MPG of offices with a GFA higher than 5000 m^2 is mostly in between 0,4 and 0,6. In some sustainable projects that are studied, the performance varies from 0,35 till 1.1. Retail scores between 0,5 and 0,8. With energy-positive buildings, the MPG becomes close to 1,0. (Levels-Vermeer & Oorschot-Slaat, 2016)

10% of the offices score 0,36 or lower and 10% score above 0,79. The median is 0,48. In offices, the standard deviation is more substantial than for residential buildings. (Nieman & Anink, 2017)

2.4.2 Life Cycle Assessment

The Life Cycle Assessment (LCA) methodology can be used to determine the MPG. The life cycle assessment is a technique to assess the environmental impacts of products, processes and materials. The impact from raw material extraction through manufacture, distribution, use, repair, maintenance, disposal and recycling can be obtained. The procedure of LCA is described in ISO14000. According to this norm, an LCA is carried out in four different phases, as explained below. (ISO-14040, 2016)

1. Goal and scope definition.

In the first step, the goal and scope are defined. In the definition of the goal, the reason for assessment is explained, the intended audience and application. Also, the functional unit of the research is defined. The scope comprises of the following elements: The functional unit, system boundary and allocation procedures. Besides, the considered impact categories are included and the assumptions made as well as limitations of the study. The functional unit quantifies the performance characteristics of a product and is, therefore, important when comparing different options. The system boundary defines the included processes and life cycle stages in the system.

2. Life cycle inventory analysis (LCI)

In the inventory analysis data of the processes and products are collected. The relevant in- and outputs are listed in various life cycle stages and drawn in a process flow diagram. The life cycle stages of considering are the production stage, construction stage, use stage and end of life stage all including transport, see figure 19. Also, category D is inserted in the LCA, including information of reuse, recovery and recycling of the product. Assessment of this module is still in development.

3. Life cycle impact assessment (LCIA)

In this phase, the collected data is assigned to the chosen impact categories and indicators, see figure 18. For all categories, environmental profiles can be calculated.

Environmental impact categories	Equivalent unit	Weighing factors [€ / kg equivalent]
Depletion of abiotic resources (excluding fossil fuels) – ADP	Sb eq	€ 0.16
Depletion fossil fuels – ADP	Sb eq[5]	€ 0.16
Global warming – GWP 100 j.	CO_2 eq	€ 0.05
Depletion ozone layer – ODP	CFK-11 eq	€ 30
Photochemical oxidant creation – POCP	C_2H_4 eq	€ 2
Acidification – AP	SO_2 eq	€ 4
Eutrophication – EP	PO_4 eq	€ 9
Human toxicity – HTP	1,4-DCB eq	€ 0.09
Fresh water aquatic eco toxicity – FAETP	1,4-DCB eq	€ 0.03
Marine aquatic eco toxicity - MAETP	1,4-DCB eq	€ 0.0001
Terrestrial eco toxicity – TETP	1,4-DCB eq	€ 0.06

Raw materials
Emissions
1-points score

Figure 18: Environmental impact categories (ISO-14040, 2016)

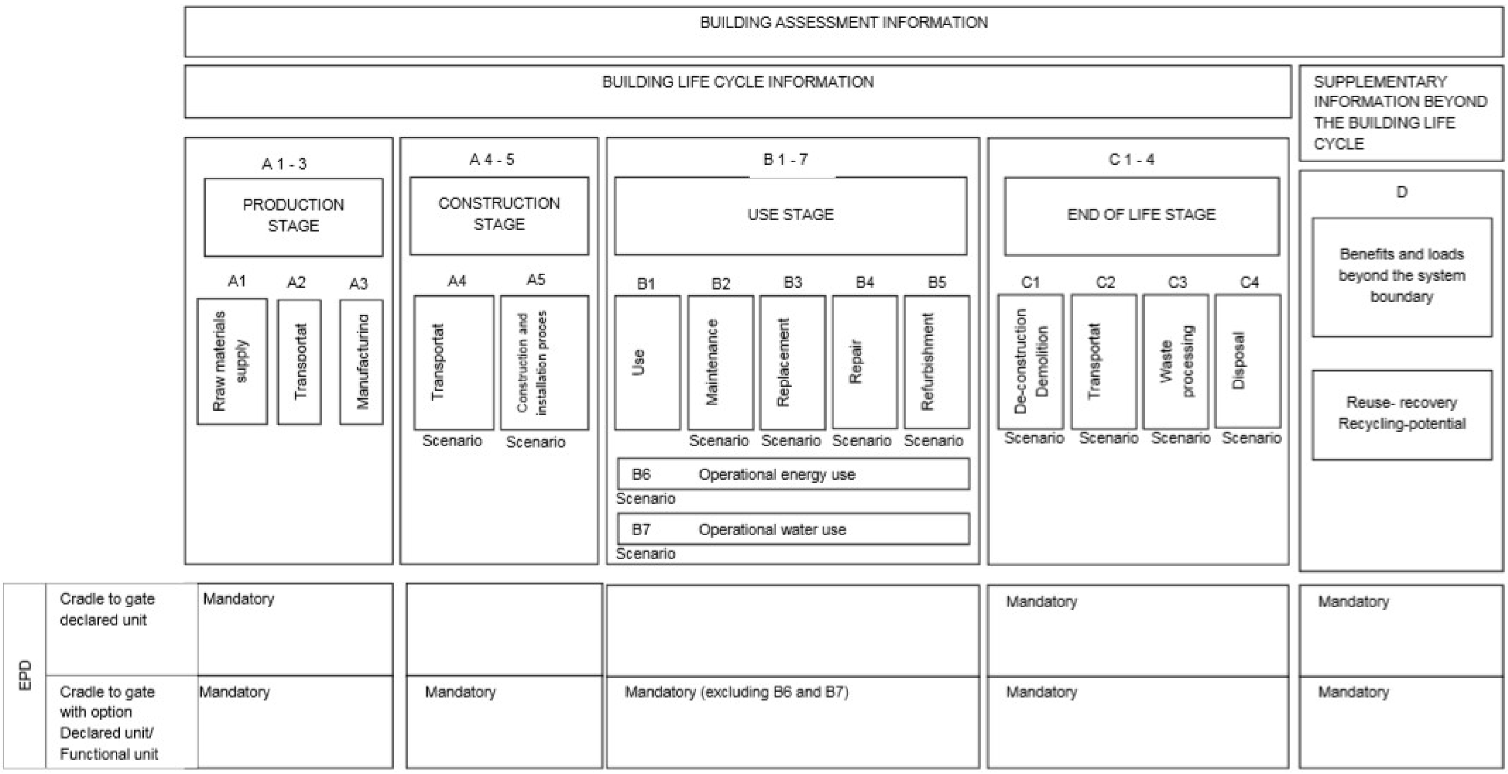


Figure 19: Life cycle stages EPD (ISO-14040, 2016)

4. Interpretation
In the last phase, the results of the previous phases are discussed and drawn in conclusions. Possible limitations and recommendations are also included.

Limitations of the LCA method

The LCA is an excellent method to show the environmental impact within the specified scope. Environmental issues outside the goal and scope are not considered, and therefore, the assessment is not a complete analysis. The 11 mentioned impact categories are all quantifiable and measurable. However, a part of the impact caused by the linear use of materials such as land use or consequences for biodiversity are not taken into account. The depletion of resources is part of the LCA, but the related scarcity is not taken into account.

An LCA calculation can show the usefulness of recycling, but the LCA does not make a distinction between downcycling and upcycling.

In the LCA the building-related energy use is also considered. When the costs are calculated, only emissions of materials are taken into account, and therefore, energy is not taken into account in the environmental cost indicator (MKI). So the MPG does not say anything about the energy use of the building.

2.4.3 Influencing building design parameters

The MPG is relatively new, and therefore, only little research is performed on this subject. In 2017 W/E adviseurs published a report of research about the principles and parameters of the environmental performance of buildings. (Nieman & Anink, 2017) Several design parameters are described which influence the MPG. Most of their research is focussed on residential buildings. In this research, it is assumed these parameters are also important regarding non-residential buildings.

Gross floor area; the influence is relative high in small apartments or offices.

Amount of floors: environmental performance of buildings with only a few floors is relatively high (so relative unfavourable)

Height of elevations: per 10% more height the environmental impact increases with 2% till 3%.

Facade area: with an increase in the facade area with an equal amount of service area, the environmental performance is increasing. An increase of 10% in the ratio of facade/floor area will result in an increase in the environmental performance of a few percents.

Open parts in the facade: Open parts in facade have a higher environmental impact than closed parts. An increase of 25% in open parts leads to a few percents higher environmental impact.

In a graduation report of Windesheim Zwolle, a study about lowering the environmental impact of offices is described. (Kampjes & Slofstra, 2019) This is done by stacking levels and replace several concrete elements by timber frames. Also, elements such as masonry and floor finishing are replaced with products that are in category 1 of the NMD. The most significant impacts and thus shadow costs are caused by facades, floors and the materials concrete and sand-lime bricks. Also, the steel used in the load-bearing structure and open parts of the facade have a high environmental impact. In the open parts of the facade, the turning parts of windows have high shadow costs. Therefore glazing that is fixed is more sustainable when considering the MPG.

PV-panels are used more and more and have an enormous environmental impact. There are different types of panels on the market which are expected to vary considerably in environmental impact. In figure 20, the impact of PV-panels is visible by compared projects with and without PV-panels. (Themagroep MPG ZEN platform, 2017)

	MPG WITH PV	MPG WITHOUT PV
Mid terrace	0,56	0,34
Corner building	0,93	0,54
Semi-detached	0,45	0,35
Corner 1storey	0,96	0,52
Apartment	0,65	0,47
Health care apartment	0,52	0,39
Detached	1,13	0,75

Figure 20: MPG values in example projects with and without PV-panels (Themagroep MPG ZEN platform, 2017)

2.4.4 Service life of buildings

The default service life of office buildings is 50 years, whereas the default value of residential buildings is 75 years. With a longer service life than the default value, the environmental impact will decrease but not in proportion to the longer service life. This is because a longer service life is only relevant for long-cyclic elements from which the service life is identical to the service life of the building. The other elements are replaced once or several times in those 50 years. (W/E Adviseurs, 2013)

The long cyclic elements in a building are mainly the framework and skin of the building (closed parts of the skin). These elements have a relatively low contribution to the environmental impact. W/E adviseurs developed a method to adapt the service life of 50 years depending on the properties of the building. This is not meant as a method to calculate the service life. It is focussed on conditions that have a negative or positive influence on the service life. Therefore, it is about the deviation of the default value. (W/E Adviseurs, 2013)

Motives of relevance for a longer service life are high functionality, extraordinary daylight or sight, high comfort, a landmark, strong identity, future-directed, a flexible layout, and an adaptable building volume. (W/E Adviseurs, 2013)

2.4.5 Discussion sustainability and environmental performance buildings

In society, a transition is taking place to more energy-efficient buildings and the use of sustainable energy sources. Therefore materials will become more and more critical in sustainability performances. The share of materials in harmful emissions will increase because of two reasons; the use of materials increases and the share of energy is decreasing.

Materials needed to increase the value of buildings and decrease the energy demand have a negative influence on the emissions to the environment and therefore, the MPG. Knowing that the MPG is significant in achieving sustainable buildings, it is essential to think in concepts, including both energy and material. The link between sustainability and materials should be known widely. Essential aspects of materials are origin, reusability, renewability, processing, and weight.

The environmental performance of buildings is a good indicator of sustainability. Hence, it is not complete to measure sustainability; other indicators are essential as well. Therefore, it is relevant to know what precisely the MPG can indicate. Definitions and context should be known when using the calculation and assessment method of the environmental performance of buildings.

A large share of the environmental impact is caused by important materials where no sustainable alternative is known of yet, for example, glazing, concrete elements, connections and installations. Also, PV-panels are mostly not made of sustainable materials. Some of the metals used in PV- panels are scarce. (Veltkamp, 2019) When these PV-cells can be produced in limited amounts, is it better to save them for locations where optimum solar heat can be gained instead of the Netherlands?

As the environmental performance decreases, the effort to reduce the environmental performance increases exponentially. What is the optimum of MPG when considering all aspects of sustainability? (Kampjes & Slofstra, 2019)

2.5 RELATION SUSTAINABILITY TERMS

In this chapter, the terms sustainability, circularity, energy performance of buildings and environmental performance of buildings are explained and related to each other.

Sustainability consists of the three pillars people, planet and profit of which the planet part is looked into in this research. Sustainable buildings are designed and built without compromising the ability of future generations to meet their needs. Therefore harmful emissions and use of natural resources should be avoided and reduced. Circular building is a method that can be used to design sustainable buildings. The energy performance and environmental performance are requirements set by the Dutch government to steer onto more sustainable building practices.

To realise sustainable buildings, it is essential to understand what building parameters contribute to both the energy use and environmental impact. Also, relations and interdependencies between those parameters and performances should be known.

As explained in 2.3, the EPG and from 2020 on the nZEB requirements are introduced to set targets for the energy performance of buildings. The most critical design parameters related to the facade to improve the energy performance are the compactness of the building, orientation, type of glass, insulation value, the existence of solar blinds, and percentage of open parts in the facade. The most substantial variation in EPG is due to PV-panels and different installations used.

From 2018 on it is compulsory to calculate the MPG for new buildings. The requirement will become tighter in the coming years to reduce the environmental impact of buildings. To reduce the MPG, the most important aspects of the design are gross floor area, height per level, open parts in the facade and installation used. Also, the choice of materials in design can reduce the MPG. As for the EPG, PV-panels have a significant influence on the MPG.

To conclude, sustainability is the ultimate goal where circularity, environmental performance and energy performance can serve as a means and method to reach this goal, see figure 21.

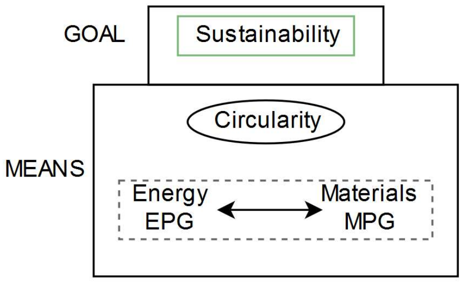


Figure 21: Goal-means relationship sustainability

3. CALCULATING THE SUSTAINABILITY PERFORMANCE OF BUILDINGS

In this chapter, an overview is given of existing tools to calculate the sustainability of buildings. The tools are compared, and a method is chosen to further use in this research. Then the relation between energy and material is analysed in existing studies. At last, the influence of insulation value is examined.

3.1 EXISTING TOOLS

In the previous chapter, it became clear that the environmental performance (MPG) and energy performance (EPG) of buildings are interdependent. Energy performance and environmental performance are both useful to steer towards more sustainable buildings. To measure sustainability, it is thus of interest to combine the environmental performance and energy performance of buildings. In the building degree, the requirements of MPG and EPG are not related to each other. (Rijksoverheid, Bouwbesluit online, 2019)

Sustainability in the building industry can be encountered differently by different actors. Investors, engineers, contractors, clients and users all have their own point of view and opinion about sustainable (re)building. Agreements between these parties can be complicated because of these different perspectives. To regulate this, several tools are developed to measure the sustainability performance of buildings. Within the existing tools or methods, sustainability is described in different ways. It can be either quantitative or qualitative. When sustainability is measured qualitative, the result is mostly shown in a number or amount of stars on a particular scale. When sustainability is measured quantitative, the results can be expressed in costs, energy or environmental impacts.

It is significant to know what the result is made up of and essential to stay critical. The weight of different aspects of sustainability can be different per tool or label. The outcome does not have to be decisive in terms of sustainability.

Figure 22: Labels of existing tools to measure sustainability

Next, an overview of different tools is given. (Rijksoverheid, Duurzaam bouwen, 2019)

3.1.1 Labels for building products

The following labels are valid to assess building products. The scale is therefore relatively small.

Dubokeur: DUBOkeur is a product of NIBE shows how environmentally friendly a product is in comparison to other products with the same application based on an LCA calculation. (NIBE, 2019)

Cradle to Cradle (C2C) is an international label for products and buildings can be awarded for five different classes: basis, bronze, silver, gold and platinum. Buildings are judged in five assessments aspects, which are: composition of materials, possibilities for reuse, use of renewable energy, sustainable water management, and social justice. (Cradle 2 cradle, 2019)

Other less well-known labels are NaturePlus, Milieukeur and Greenworks.

3.1.2 Labels for buildings

The following labels or methods to express the sustainability of buildings are focussed on the whole building. Also, the environmental performance and energy performance are limited to the level of buildings to be able to compare and set clear boundaries. However, this influences the results of performances and also the level of sustainability. This means good results within these labels and tools cannot directly be seen as more sustainable. The results have to be judged within the overall context.

GPR-Gebouw (Gemeentelijke Praktijk Richtlijn) is a software tool to express the sustainability of buildings. It divides sustainability in 5 different themes, namely energy, environment, health, users quality and future value. The tool is developed by W/E adviseurs. In each theme, the building is rated on a scale of 1 to 10. The total GPR score is translated into a quality label of one to five stars. One star means a rate of 6, is equal to the level of the Building Decree. (GPR gebouw, 2018) (Agentschap NL Energie en Klimaat, 2019)

BREEAM (Building Research Establishment's Environmental Assessment Method) is a commonly used method to express sustainability performances of buildings developed by DGBC. The method is comparable with GRP-Gebouw but more extensive. Buildings can be evaluated in development and delivery phases based on different subjects, grouped in the following categories: Management, health, energy, transport, water, materials, waste, land use and ecology and pollution. In BREEAM, energy and materials are both important indicators. The total weight of energy in BREEAM is 19%, and the total weight of materials is 12,5%. (DGBR, 2014) These weights are not only based on energy and emissions but also on the market, consumption, and whether people want to invest or not. (Buijs & Scheele, 2016) Unfortunately, a BREEAM certificate is expensive and therefore not accessible for everyone.

LEED (Leadership in Energy and Environmental Design) is developed by the US Green Building Council (USGBC) and is a method to certificate and evaluate the sustainability performance of buildings. It is based on a scoring system making use of a checklist. (USGBC, 2019) LEED is derived from BREEAM. LEED makes use of international standards while the requirements in BREEAM are adjusted to local situations. (Verweij, 2019)

DPG (Sustainability Performance Buildings): The DPG is a method to combine the EPG and MPG and is based on the procedure to calculate the MPG. To appreciate the total sustainability performance, it is obvious to align the system boundaries, assessment method and dimension to the environmental performance of buildings. This environmental performance already is based on the LCA methodology for integral evaluation of environmental impacts of products. The choice for MPG as a basis for the DPG means that the EPG must be converted as accurately as possible into impact scores that are consistent with the MPG. (Alsema, Anink, Meijer, Straub, & Donze, 2016) This does have some drawbacks because the system boundaries of EPG and MPG are different and also the functional units differ. In the EPG, 'm^2 per heated area' is used as a unit while in the MPG, 'm^2 per gross floor area' is used. (Korbee, 2017)

The calculated energy use in the EPG is converted into environmental impacts with impact factors. The total impact as a result of energy use is the EPG*. Then it follows DPG = MPG + EPG*. Within the TKI-KIEM project, the impact factors are identified for the two most important energy carriers: electricity and natural gas. The energy use in kWh or m^3 is multiplied with an environmental impact factor and are then summed. (W/E Adviseurs, 2016) Sustainability is then calculated with the following formulae. (Grefelman & Weerd, 2014)

$$Sustainability = \frac{\sum(Eg;tot * femissie) * 0,05}{BVO} + \sum\frac{(M * SK)}{BVO * T}$$

When the DPG would be used more in practice, the question is if a boundary value should be set to this performance as for the EPG and MPG. To have three performance requirements in the building degree seems a little excessive. But when substituting the EPG and MPG the administrative burdens would reduce. (Backes, Boeve, Koolhoven, & Versteeg, 2018)

CPG (Circularity performance buildings): In the CPG, the circularity performance of buildings is measured. The CPG is an extension of the DPG, the results of DPG are used, and some extra criteria are tested. The CPG is included in GPR-Gebouw; the results from this tool can directly be used to calculate the CPG. The input is converted into a score between 1 and 10. The scores in subcategories are summed and will result in the CPG. However, this method is qualitative; there is still no method in which the circularity of buildings can be determined quantitatively. Circularity is still playing no role in the tenders and investments because juridical it is difficult because circularity is challenging to measure. (Mak, 2019)

3.2 SUSTAINABILITY PERFORMANCE OF BUILDINGS

In the previous section, various ways to assess the sustainability of buildings have been discussed. Essential differences in the assessments are the variables that are measured and whether it is qualitative or quantitative. In table 1, an overview is given of the different tools.

Table 1: Overview of different tools/methods

Tool	*Measured unit*	
GPR-Gebouw	Mark	Qualitative
BREEAM	Mark	Qualitative
LEED	Mark	Qualitative
DPG	€/m^2	Quantitative
CPG	Mark	Qualitative
EPG	CO_2 emissions, €/m^2 or energy	Quantitative
MPG	€/m^2 or emissions	Quantitative

The methods that evaluate the whole building are further elaborated because this corresponds with the EPG and MPG and therefore, the scope of research. At building level, energy and material are both relevant. At product level, the energy use in a building is not taken into account. The tools GPR-Gebouw, BREEAM, LEED and also CPG, measure in a qualitative way and express results in a mark in a scale of 1-10. The DPG is expressed in shadow costs, €/m^2 and is quantitative as the MPG and EPG.

The discussed tools GPR-Gebouw, BREEAM and LEED, are mostly useful for companies to get a certificate or to show their building has a lot of value in terms of sustainability. The tools are less suited for scientific basis. First, because the tools are qualitative. For sustainability, it is important to know the quantity of damage to the environment. The second reason is that the weight in BREEAM is not only established by sustainability but is also affected by market forces. In BREEAM, 19% of the total score is ascribed to energy and 12,5% to materials. When considering the energy consumption of both categories, the energy used in the building during the service life is three times as much as the energy used for the production of materials. When considering the shadow costs, the energy use contributes 10 times as much as material production. (Buijs & Scheele, 2016) In this knowledge, it seems logical to focus on energy efficiency and energy reduction. However, these facts are based on a study in which nine office buildings are analysed. A transition is ongoing towards energy-neutral buildings and use of sustainable energy sources. The energy impact will decrease, and the material impact will increase. Therefore, innovations must be emphasized on the impact of used materials as well.

GPR-Gebouw is a tool that calculates the energy and material performance (DPG) and besides, takes into account three other categories. The outcome is qualitative. The CPG is an extension in GPR-Gebouw. It is useful to assess circularity, but there is no method yet to determine circularity in a quantitative way. Therefore of the existent methods, the DPG is the most accurate model to combine the energy and material impacts.

The environmental performance of buildings can be expressed in money (shadow costs) or in harmful emissions. These emissions are of different substances and cannot be summed. The energy performance can be expressed in energy, CO_2 emissions or environmental costs. When choosing the DPG to evaluate the sustainability of buildings, the sustainability will be expressed in shadow costs. In the environmental performance, 11 impact categories are taken into account which are possible to quantify. Some environmental damages, such as land competition or water use, are not possible to express in emissions but do play a role in the sustainability performance of measures.

The title of this thesis reads 'When energy savings become a waste'. The question when energy savings (by adding extra material to a building) become a waste (because it costs more energy to produce than energy demand is reduced) is not answered by expressing the sustainability performance in shadow costs. Therefore it is relevant to look at the energy saved by adding more material and the energy used by the manufacturing of these materials. Then the embodied energy of the products is compared with the reduction of the energy demand. There an optimum can be found, for example for insulation thickness:

$t_{optimal} = t_{tmin(embodied\ energy\ –\ energy\ reduction)}$

When considering only the total energy use of measurements the assessment of sustainability would not be sufficient. Only the effects of energy use, expressed in CO_2 emissions, will then be taken into account. Yet, other emissions are left out of consideration. As a result, both the sustainability performance and the total energy use are relevant when comparing different scenarios. Therefore, the aim in the variation study is to consider the combination of energy and material both in shadow costs and expressed in energy.

3.3 ANALYSIS RELATION ENERGY AND MATERIALS

3.3.1 Introduction analysed variants

Various research is conducted about the influence of energy performance on environmental performance, analysed in this paragraph. Less research is done on the influence of nZEB on MPG. It is only demonstrated that the nZEB requirements of 2015 are only feasible when all the stops are pulled out. (Kruithof A. , 2016) Especially the first nZEB requirement is tough to accomplish.

A study with variations to analyse existing houses and the relation of MPG, EPG and nZEB is conducted and published by DGMR. The concept requirements and temporary methodology of the nZEB are applied. In this study, four types of residential buildings are chosen: a one-storey corner building, a semi-detached house, apartment and a detached house. The study is executed with the NMD1.8, but also the results calculated with the NMD2.0 are included (with the correction factor of 0,4). The analysed buildings are relatively new. Therefore, the basic situation has a high insulation value, a high-efficiency kettle and has enough solar panels to fulfil the second and third nZEB requirement. Regarding these houses, the variants summed in table 2 are analysed. (Themagroep MPG ZEN platform, 2017)

Table 2: Analysed variants

	1.Basis
Insulation level	2. Building degree level of insulation 3. Passive building concept level of insulation
Geometry	4. Increase percentage of glass with 25% 5. Reduce compactness with 10% (+ 10% facade and roof) 6. Reduce compactness with 30% (+ 30% facade and roof)
Different installations used	7. Ground heat pump 8. Air heat pump 9. District heating 10.Biomass 11. Solar boiler
PV-panels	12. Vary the amount of PV panels; PV on the roof at the back 13. Vary the amount of PV panels; PV on the roof at the front and back 14. Increase the service life of PV-panels to 32,5 years

3.3.2 Analysis EPC

In figure 23, the EPC is plotted for different variants for the different building types. Remarkable is that the EPC is much lower than the requirements stated in the building degree (EPC=0,4) when fulfilling the nZEB requirements. Especially the different installations used and variation in the amount of PV panels has a significant influence on the EPC.

Insulation level

The influence of the insulation level on the EPC value is marginal. It is remarkable that the insulation used at the level of the building degree has a better EPC score for all types than the passive house level.

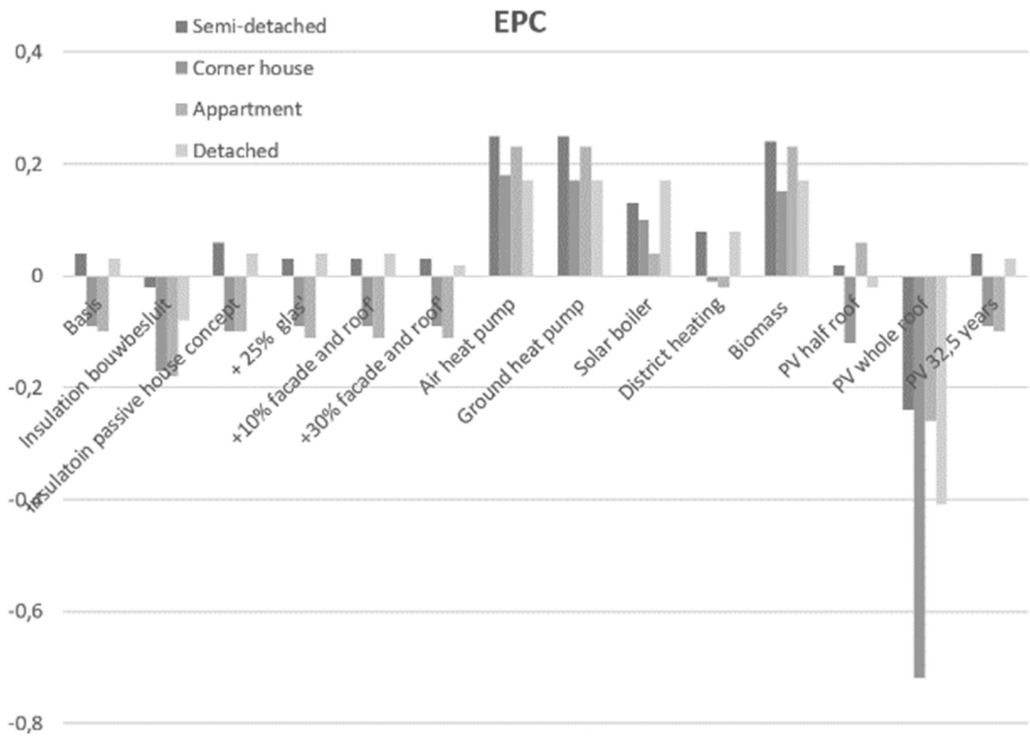


Figure 23: EPC for different measures. Based on (Themagroep MPG ZEN platform, 2017)

Geometry

The geometry has even less influence on the EPC than the insulation. Also, with 30% more facade and roof, there is no difference compared to the basis insulation, while the surface is larger and thus more heat loss occurs. This is because of the chosen project where there is already a lot of insulation, and the rate of infiltration is low.

Different installations

The different installations have a negative influence on the EPC. This is because the new installations use (partly) sustainable energy and therefore fewer PV-panels are needed. So these results do not directly say something about the energy performance of the building.

PV-panels

The biggest variations in EPC are due to the addition of PV-panels. Especially for the corner house, a huge decrease of EPC is visible in figure 23. This is because the house is only one storey high, so the area of the roof is respectively very large compared to the floor area. Also, in the other types, the EPC is very low in this scenario. An increase in service life does not influence the EPC.

3.3.3 Analysis MPG

In figure 24, the MPG is plotted for different variants for the different building types. Especially the type of building has a lot of influence on the MPG. The different adjustments influence the MPG slightly. For the corner houses, most variations can be seen. Also, when regarding the MPG, the increase of PV panels cause a significant difference.

Insulation level

The influence of insulation value on the MPG is dependent on the underlying assumptions of the basic variant. In the corner and detached building, there was a lot of insulation necessary to fulfil the nZEB requirements. When adding more insulation, the MPG increases slightly.

Geometry

The increase of materials in the facade has a limited influence on the MPG. Only the detached buildings score higher than the requirement of 1.0. This is because this type of building already has a relatively large glass percentage and a relatively unfavourable ratio of skin and floor area.

Different installations

The MPG of variations with different installations are lower because fewer PV-panels are needed to achieve the same energy requirements. This indicates that PV-panels have more influence on the score of the MPG than the installations.

PV-panels

The scenario with PV-panels on the whole roof has for all four building types the highest values of MPG. Increasing the service life results in a small reduction, almost nothing for semi-detached and detached buildings and a bit more for the other types. This also has to do with the starting conditions.

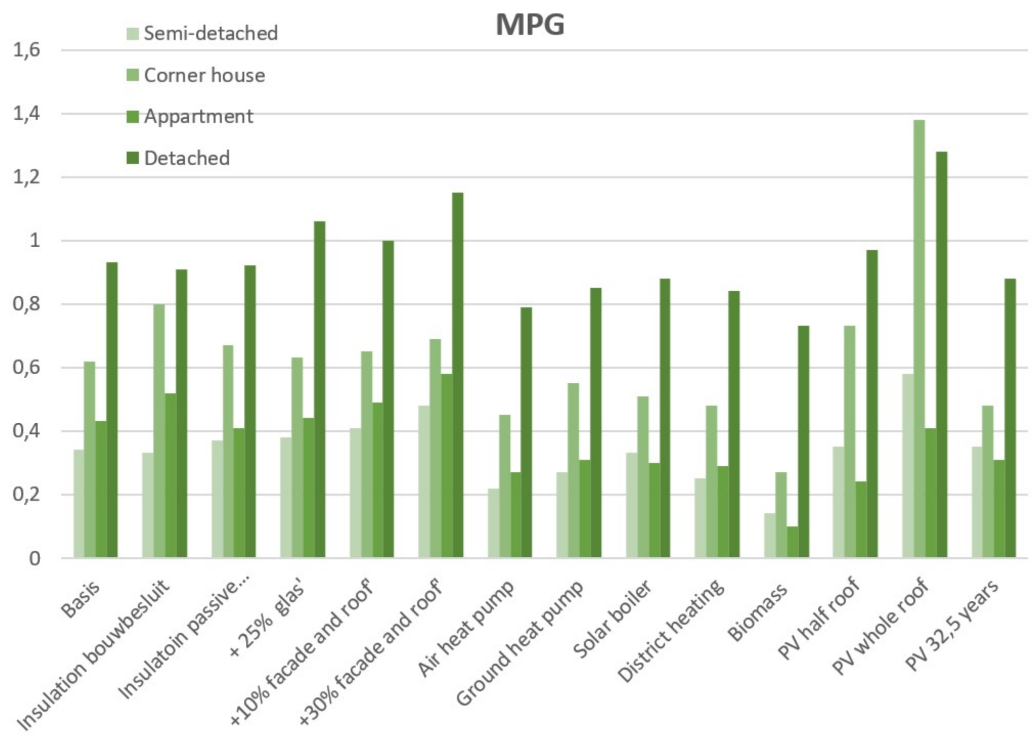


Figure 24: MPG for different measures. Based on (Themagroep MPG ZEN platform, 2017)

3.3.4 Analysis combination EPC & MPG

From these results, it becomes clear that in the EPG as in the MPG the design of the building and type of building is crucial for the outcome. Remarkably, the geometry and extra insulation do not have a significant influence on the EPG and MPG. The latter is also visible in figure 25. The effects of insulations thickness on the environmental impact are minimal compared to other measures.

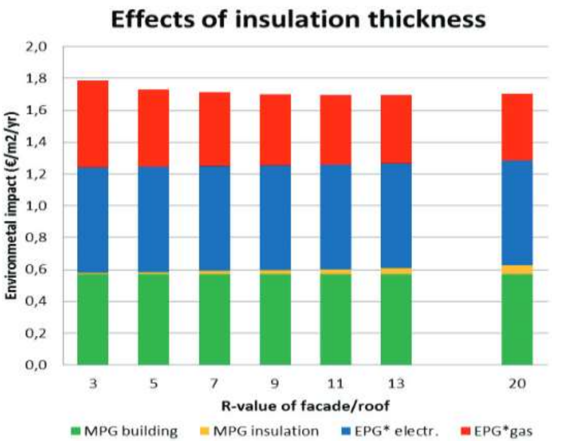


Figure 25: Effects of insulation thickness on the environmental impact (Alsema, Anink, Meijer, Straub, & Donze, 2016)

When comparing the EPG and MPG for different measures, it becomes clear that the indicators are indeed interdependent. When the EPG becomes lower, the MPG becomes higher and vice versa, see figure 26. However, this is not always the case.

3.3.5 Findings in analysis

From this analysis can be concluded that the EPG and the MPG mostly depend on the type of building instead of changes in the design. When the nZEB requirements are fulfilled, it becomes clear there is a shift in impact from energy towards material, and therefore material used becomes more important. When PV panels are included in the design a large decrease in EPG and increase in MPG is visible in the results. One crucial observation is that adding more insulation does not significantly change the MPG or EPG. The trend is to add more insulation in new buildings, so with this outcome, the question arises whether that is sustainable or not.

From this analysis can be learned that it is meaningful to analyse the meaning of the results with the boundary conditions and assumptions. In the analysed study certain limits and requirements are set to fulfil some conditions and therefore the basic variant is adjusted in some other variations.

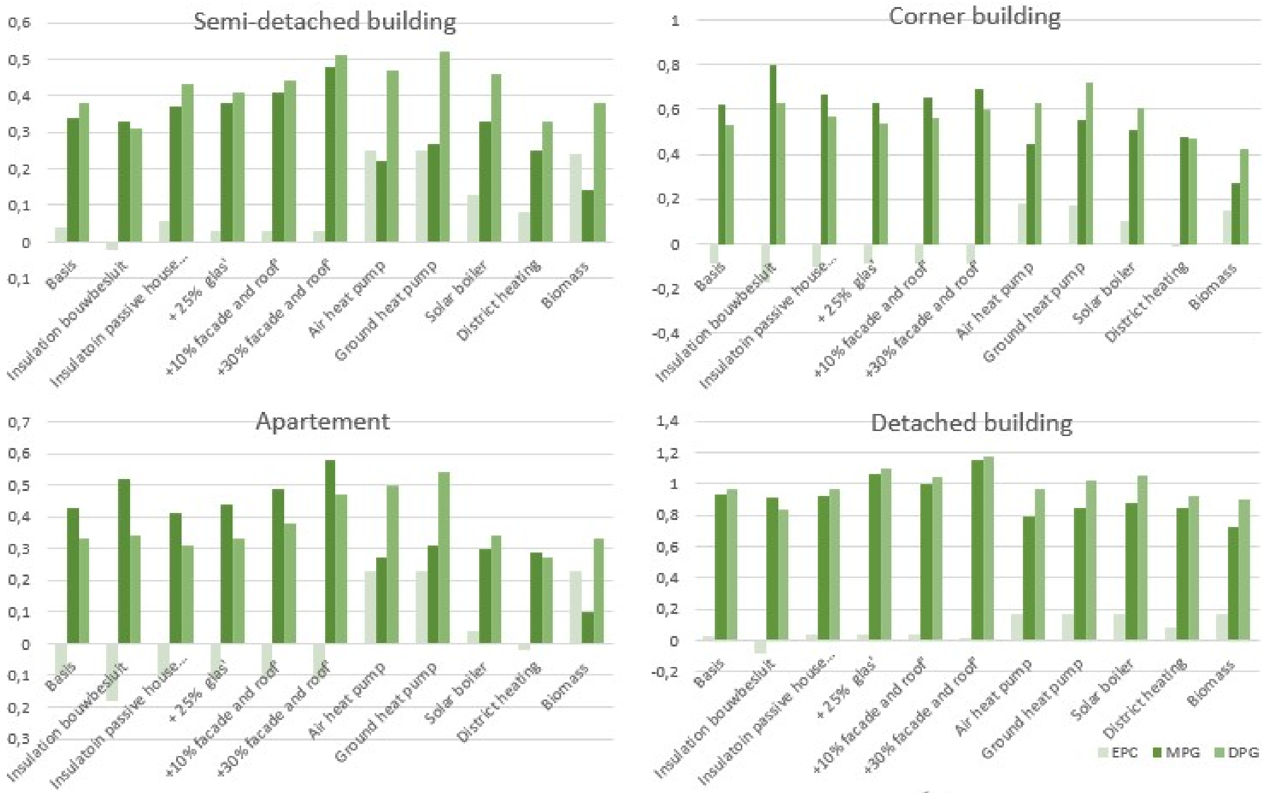


Figure 26: EPG & MPG of different building types

3.4 INFLUENCE INSULATION THICKNESS

3.4.1 Reference offices

In the previous section, various research on MPG and EPG of residential buildings is analysed. One interesting finding for the facade design is the small influence on the insulation thickness on the EPG as well as the MPG. It is relevant to look into this in more detail because it is one of the first measures one will think of when enhancing the sustainability of a building.

In this paragraph, several example calculations are shown that look further into this aspect. Underlying assumptions in these calculations are the insulation values according to the building degree. This holds R_c values for facades, roofs and floors of respectively 4.5 m^2K/W, 6.0 m^2K/W and 3.5 m^2K/W. The U-value for windows is 1,65 m^2K/W. (Rijksoverheid, Bouwbesluit online, 2019) In the following calculations, the R_c value of the facade will be varied.

In these calculations, three office buildings are used as a reference, as described in 'Referentiegebouwen BENG'. *(DGMR, 2016)* The EPG and MPG of a small office, medium office and large office buildings are analysed. Tools being used are MPGcalc and Uniec2.2. The measurement and amount of layers are shown in figure 27. Three office buildings are analysed, a small

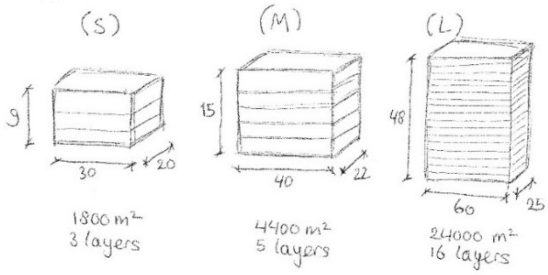


Figure 27: Reference office buildings

office with a floor area of 1800 m^2, a medium office with floor area 4400 m^2 and a large office with 24000 m^2. The percentage of glass used in the three office buildings is determined based on the shape factors of Arcadis. The percentages are respectively 40%, 33% and 50%. (Brand, Roozendaal, Peppelman, & Wind, 2016) 10% of all the roofs are used for PV-panels.

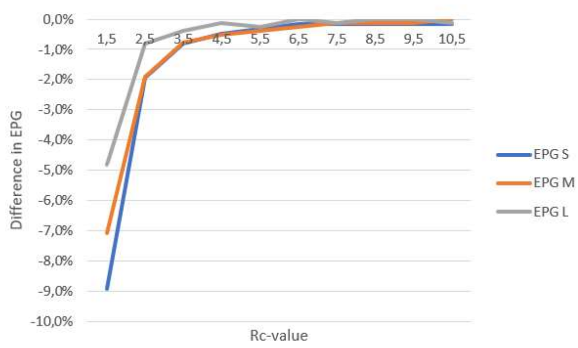


Figure 28: Difference in % EPG when varying the Rc value

3.4.2 Energy performance

When varying the insulation value, the energy performance decreases as the Rc value increases. See the results in table 3 and figure 28. The relationship is not linear. Below the required R_c value for facades of 4,5 m^2K/W the decrease in EPG is more than from 4,5 m^2K/W onwards. The EPG value included a lot of different aspects. The R_c value of the facade only influences a small part. The larger the building, the smaller the influence. When considering the difference in energy demand, the results are more relevant. In figure 29, the heating demand in different scenario's is plotted against the R_c value. The heating demand has a substantial increase in the first step from 0,5 m^2K/W to 1,5 m^2K/W. Furthermore, after 4,5 m^2K/W some decrease in energy demand is visible, but it relatively small.

Table 3: Results EPG of different offices

Rc value	*EPG S*	*EPG M*	*EPG L*
0,5	0,683	0,849	0,791
1,5	-8,9%	-7,1%	-4,8%
2,5	-1,9%	-1,9%	-0,8%
3,5	-0,8%	-0,8%	-0,4%
4,5	-0,5%	-0,5%	-0,1%
5,5	-0,3%	-0,4%	-0,3%
6,5	-0,2%	-0,3%	0,0%
7,5	-0,2%	-0,1%	-0,1%
8,5	-0,2%	-0,1%	0,0%
9,5	-0,2%	-0,1%	0,0%
10,5	-0,2%	0,0%	-0,1%

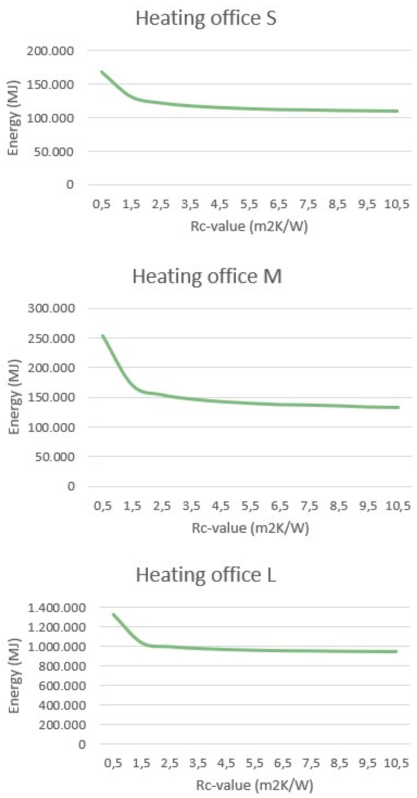


Figure 29: Heating energy for S, M and L offices

These results are explicable by the following formula;

$U = \frac{1}{R_{tot}} = \frac{1}{R_{se}+R_c+R_{si}}$ (Linden, 2011)

For an insulated wall stands $R_c = 0{,}2 + \frac{t_{insulation}}{\lambda_{insulation}}$

For example, for a glass wool insulated wall, the thermal transmittance by varying insulation thickness is visible in figure 30.

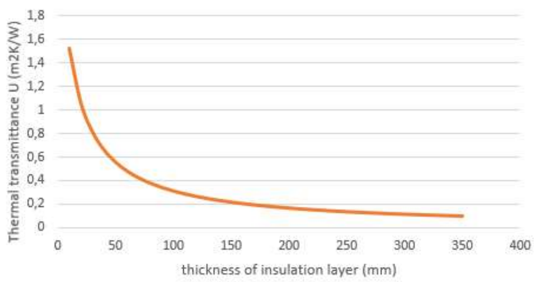
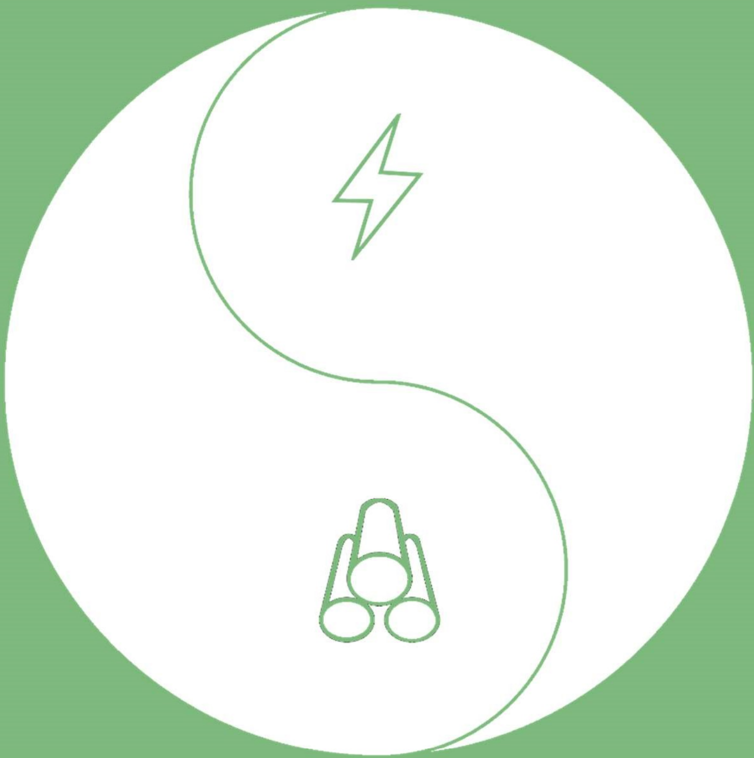


Figure 30: U-value glass wool insulation

To conclude, this study shows that insulation values higher than 3,5 m^2K/W only cause a small improvement in the EPG. It is, therefore, expected it would not improve the sustainability performance, further analysed in the case study in 4.4.3.

4. CASE STUDY FACADE DESIGN



In this chapter, the one-factor-at-the-time (OFAT) analysis of facade parameters is explained. First, the relevance of the study is shown in 4.1, then, the reference office is elaborated, and existing calculations are explained in 4.2 and 4.3. Furthermore, the calculated variants are illustrated in sections 4.4 and 4.5.

4.1 RELEVANCE FACADE DESIGN CASE STUDY

From both architectural and engineering perspective, the facade is of great importance and decisive in design. The facade is not only the appearance of the buildings but has a lot of functions and requirements to fulfil. Essential functions of the facade are thermal comfort of the building, transparency, waterproof, fire protection, ventilation, stability, internal health, acoustics, and architectural quality of the building. The facade can also be used to produce energy.

The facade of a building comprises an interesting combination of energy performance and material use. The facade can reduce the heating demand of the building when achieving a high insulating value or by adjusting the design. It is also possible to gain energy, which results in a decrease in energy gained from other sources needed. In most of these scenarios to improve the energy performance, much material is added to the building. Therefore the design of the facade can make a significant difference in both the MPG and EPG.

The facade of a building exists of a lot of different components such as structural elements, closed parts, windows, joints, ventilation in- and outlets and doors. Therefore the design of facades is very complex and has to fulfil a lot of requirements.

The average share of the facade in the environmental performance of office buildings is 25%. (Movares, 2014) The facade has the most variation in the share in MPG of all elements of the building, see figure 32. Because the facade has such a significant influence in both material- and energy performance, in this research, the design aspects reducing impact and energy use are explored.

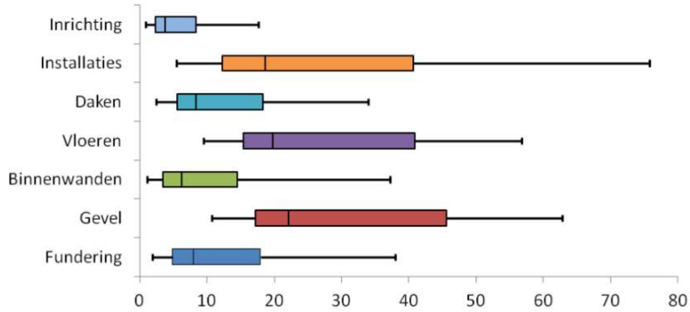


Figure 32: Variation in share shadow price per building part, contribution to shadowcosts on horizontal axis (Movares, 2014)

4.2 REFERENCE OFFICE BUILDING

In this chapter, the influence of several facade design parameters on the MPG and EPG will be evaluated using a one-factor-at-a-time analysis. This will be done using a specific case study. The EPC and MPG of an existing office building will be calculated, the reference office, see figure 31. Several adjustments are made to this existing situation to encounter the influence of these aspects. The first goal is to give an overview of the parameters that can make a big difference and the ones that are not relevant. Afterwards, the relevant parameters can be evaluated in more depth. Then, an optimal scenario in terms of environmental- and energy performance can be established.

Figure 31: Impression reference office (Source: confidential)

General information

The reference building is a detached office building built in 2017, consisting of 4 storeys. The building is chosen because of its size, available data and representative of office building trends. The total user area is 4567 m^2, which is medium-sized according to the RVO (DGMR, 2016). Most offices in the Netherlands are medium-sized, and therefore, the results will be most useful. The facade area is about 2/3 of the user area. The size of the building is significant for the energy demand and material use. The larger the building, the less loss area.

Facade

The share of the facade in the environmental impact of this building is relatively large compared to other buildings, 40% of the environmental performance of the building is due to the facade. Therefore there is a lot of room for improvement. The east and west facades have a curtain wall facade system, Schüco FW50+-SI, see figure 34 and 35. This system consists mostly out of aluminium profiles and triple glazing, see figure 33. Also, the building has vertical louvres, from now on called 'louvres' The louvres are also made of aluminium. The north and south facades are entirely closed and made of NVPU-PU insulation and aluminium sheeting. The structural system consists of wide slab floors, concrete walls and a steel structure in the facade. In total, the facades consist of 80% out of glass. In building trends of office buildings, an increase can be seen in the use of glass in the facade.

Installations

Furthermore, the building has PV panels on the roof and a heat pump to provide heating. The ventilation is entirely mechanical, and some windows can be opened in the facades.

Performances

The energy performance of this building and environmental performance of this existing building are used as reference situation. Two different tools will be used to make these calculations. To calculate the environmental performance of buildings, MRPI gebouw is used. (W/E adviseurs, 2019) MRPI is a registered life cycle analysis based method for producers of building products to display the environmental aspects of their products. MRPI/EPD certificates are used by producers who want to profile their product in terms of sustainability. With this certificate, the products can be included in different databases used in environmental performance calculations. A new certificate costs €1500 and also registration costs are obliged. (NVTB, 2019) W/E adviseurs developed the MRPI tool, a free online tool to calculate the MPG. This tool is chosen in this research because in the output, next to the different impact categories, also the energy use (both renewable and non-renewable energy) is given.

For the energy performance calculation, Uniec2.2 is used. This is an online tool suitable for energy performance calculations. Uniec 2 is attested by KIWA according to BRL 9501 (the assessment regulation for EPC calculations). (Uniec2.2, 2019) The calculations are made based upon NEN7120, NEN8088 and NEN1068. Uniec 3 is in development to calculate the nZEB indicators that are active from January 2020. Uniec 3 computes according to NTA8800. Uniec 2.2 also shows the temporarily nZEB indicators but are not entirely accurate because the calculation is made with the old norms. Therefore, the current results of the new nZEB requirements are indicative.

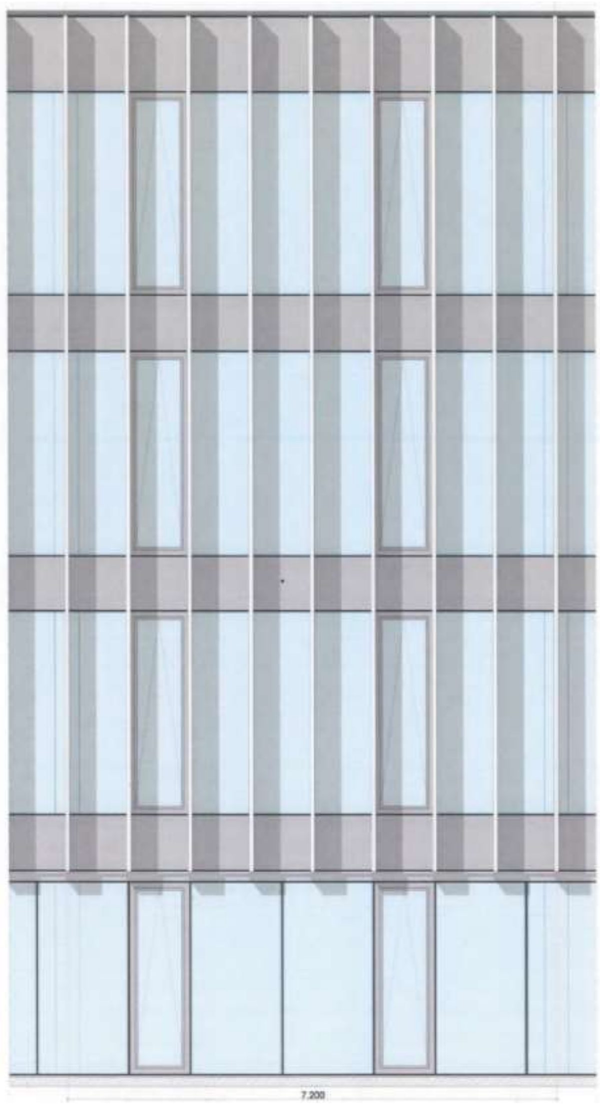


Figure 33: Drawing facade reference building. (Source: confidential)

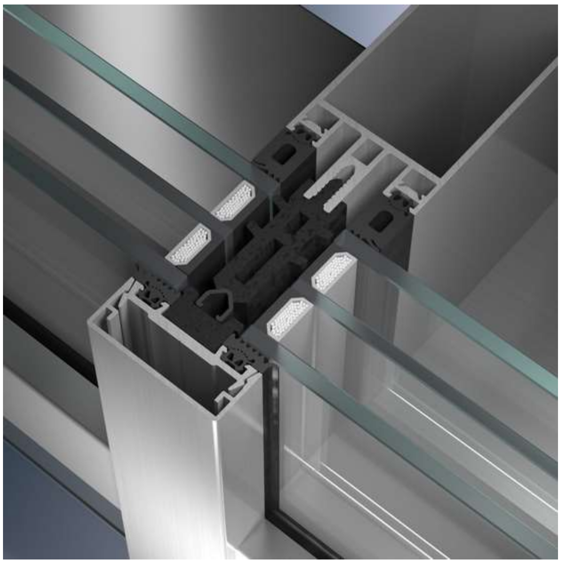


Figure 34: Impression detail Schüco section facade (Schuco, 2019)

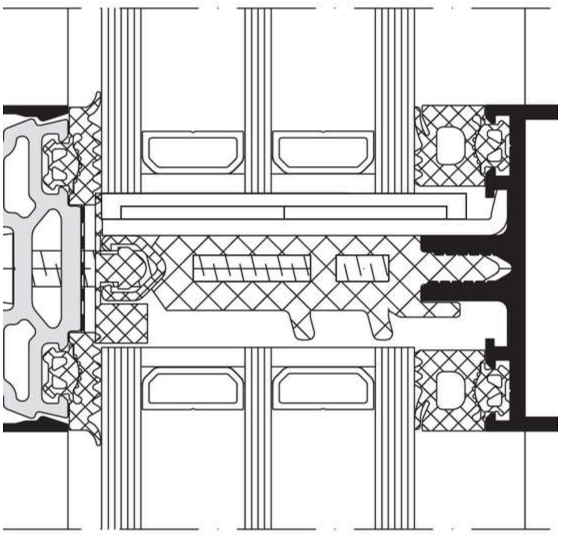


Figure 35: Detail Schüco section facade (Schuco, 2019)

4.3 EXISTING BUILDING CALCULATIONS

The office building that is used as a reference is obtained by the company Dutch Green Building Council (DGBC). DGBC is not the owner of this building. DGBC is a company that certifies buildings with the BREEAM certificate. There are a lot of documents and calculations needed to get this certificate, including calculations of the energy performance and energy performance. DGBC is not the one making these calculations. Extern parties provide the required documents of which DGBC will check the results and determines for which certificate the building is eligible. The calculations are checked at random, so not all scores and calculations are accurately checked by DGBC.

Some assumptions about the building have to be made because the data is the reference office is not complete. Only data available of existing environmental performance and energy performance is known.

4.3.1 Energy performance calculation

For this project, the energy performance calculations with which the building permit was requested was different from the energy performance calculation of the realisation. This shows that the method to certify buildings and to request building permits is not entirely accurate. The existing energy performance calculation of the office building is made with ENORM V3.10 on 20th of June 2016. The realistic energy performance calculation of the building is made on 3th of October 2017 with ENORM V3.41. These calculations are made with different versions, so this can also cause differences in the outcome. The result of the first calculations is E/E=0.387. In the second version, it is slightly decreased to E/E=0.352.

To be able to compare the results of the variants in table 4, an overview is given of the heating, cooling and energy demand of the reference office building, made visible in figure 36. In appendix C, the whole calculation can be found. The total energy demand of the building is 1.066.513 MJ

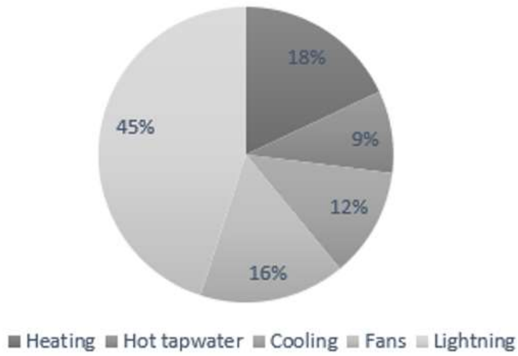


Figure 36: Yearly primary energy reference office

In this calculation is was remarkable that the areas of the north and south facade surface in the calculation do not correspond to the real facade surfaces. The area of the north and south facade in the calculation as in the transmission calculation is 114 m^2. The building is 15,2 m tall, 86,40 meters long and 21,60 m in width. This means the north/south and east/west facades of the building would respectively be around 328,32 m^2 and 1313,28 m^2. The area used in the calculation is 1260 m^2 and 114 m^2. The area of the roof would be around 1866 m^2, the used area in the calculation is 1301 m^2. Some differences might be caused because the length, width and height are not constant over the whole building; the building consists of a combination of three rectangular volumes. When calculating the areas based on drawings, the east and west facade are 1250,6 m^2. This is quite close to the value used in the calculation. However, the north and south facade are each 302,6 m². This is more than the doubled used value of 114 m² in the calculation. This means that there is actually more energy needed to compensate for the transmission losses. There is also one variant calculated with actual transmission losses. The EPC of this variant is 0,247, so the difference is only 0,01 and therefore 4% more than calculated. Therefore it is not significant. However, it might influence other parameters, so it is essential to stay as close to reality as possible in this calculation. For example, one difference caused by this variation is that the percentage of open parts is, in reality, less than 80%. In the calculations, the values of the reference calculations are used to compare with. In this research, the results are analysed relative to the reference situation to compare the scenarios. It is not about the actual values of energy and environmental performance.

The calculated energy performance is 0,237. This is significantly lower than 0,352. The difference in the calculation is mostly caused by a lower calculated energy need for hot tap water.

Table 4: Energy performance reference office

Yearly primary energy	
Heating $E_{H;P}$	157.030 MJ
Backup power supply	68.703 MJ
Hot tap water $E_{W;P}$	103.705 MJ
Backup power supply	1.063 MJ
Cooling $E_{C;P}$	92.948 MJ
Backup power supply	39.837 MJ
Summer comfort $E_{SC;P}$	0 MJ
Humidification $E_{hum;P}$	0 MJ
Fans $E_{V;P}$	192.331 MJ
Lightning $E_{L;P}$	532.583 MJ
Area	
Total users area $A_{g;tot}$	4.235,00 m²
Total loss area A_{ls}	5.036,20 m²
CO_2	
CO_2-emission m_{co2}	17.917 kg
Energy performance	
Specific energy performance EP	69 MJ/m²
Characteristic energy use E_{Ptot}	292.329 MJ
Allowable characteristic energy use $E_{P;adm;tot;nb}$	1.237.212 MJ
E_{ptot} / $E_{P;adm;tot;nb}$ (building decree)	0,24 -
E_{ptot} / $E_{P;adm;tot;nb}$ (energy label)	0,17 -
Energy label new utility buildings	A++++
nZEB	
Energy need	59,2 kWh/m²
Primary energy use	19,2 kWh/m²
Share of renewable energy	66%

4.3.2 Environmental performance calculation

Also, the existing environmental performance calculation of this building is used, and a few remarkable points are summed below.

The facade has a contribution of 40% to the total environmental impact, see figure 37. Aluminium and glass have the largest share in this impact. It is remarkable that the insulation of the facade has a minimal effect, smaller than one per cent.

In the calculation of the energy performance, the insulation value of the facade is set as 4,5 m²K/W. In the environmental impact, the insulation is filled in as 6 m²K/W. This is probably an error because this is the standard value in the tool, and only the area is adjusted. It is not significant in the calculation, but it is a sign that there can be made mistakes easily without anyone noticing.

In the results of the environmental performance, the list of materials is strikingly short. The curtain wall results in only a few materials for the facade, but there are for example no stairs taken into account in the calculation although the building has concrete stairs which have a significant influence on the total score. The number of materials in this kind of calculations and masses of, for example, the steel used are hard to trace back and to check.

The existing calculation as given is used as input for the reference scenario. The impacts of the reference situation are shown in table 5.

Because other tools are used in the calculation, not everything can be converted directly. Some values are still unknown, so the following assumptions had to be made in input, which resulted in a difference in scores. The MPG of the reference situation is 1,12 instead of 1,22, and the EPG is 0,237 instead of 0,352.

In the database of MRPI, there is no wall paint, so this is not taken into account in the environmental performance of the building. The wall paint is only less than 1% of the total environmental impact and is therefore not added. In the cooling part, no efficiency can be filled in so these could be different. Also, the lightning cannot be exactly filled in as in the existing calculation. For the solar collector, the mandatory parameters in Uniec2.2 such as the volume are not known, so the assumption is made by reference to online products. (Daalderop, 2012)

MPG	1,12
Environmental effects for building decree	
Fossil fuel depletion	5.17E-002 kg Sb eq.
Global warming (100 years)	9.75E+000 kg CO_2 eq.
Milieueffect	**Ehd / m2 BVO*jaar**
Abiotic resources depletion (excl. fossiel)	5.34E-004 kg Sb eq.
Fossil fuel depletion	5.17E-002 kg Sb eq.
Global warming (100 years)	9.75E+000 kg CO_2 eq.
Ozone layer depletion	7.63E-007 kg CFK-11 eq.
Photochemical Oxidation (smog)	4.61E-003 kg C2H2 eq.
Acidification	4.50E-002 kg SO2 eq.
Eutrophication	7.12E-003 kg PO4 eq.
Human toxicity	3.66E+000 kg 1,4-DCB eq.
Freshwater Aquatic Eco-Toxicity	8.70E-002 kg 1,4-DCB eq.
Marine Aquatic Eco-Toxicity	3.71E+002 kg 1,4-DCB eq.
Terrestrial Eco-Toxicity	4.78E-002 kg 1,4-DCB eq.
Indicators	
Total renewable energy	10,87 MJ
Total non-renewable energy	120,11 MJ
Energy	130,95 MJ
Water use	3,67 m^3

Table 5: Environmental performance reference office

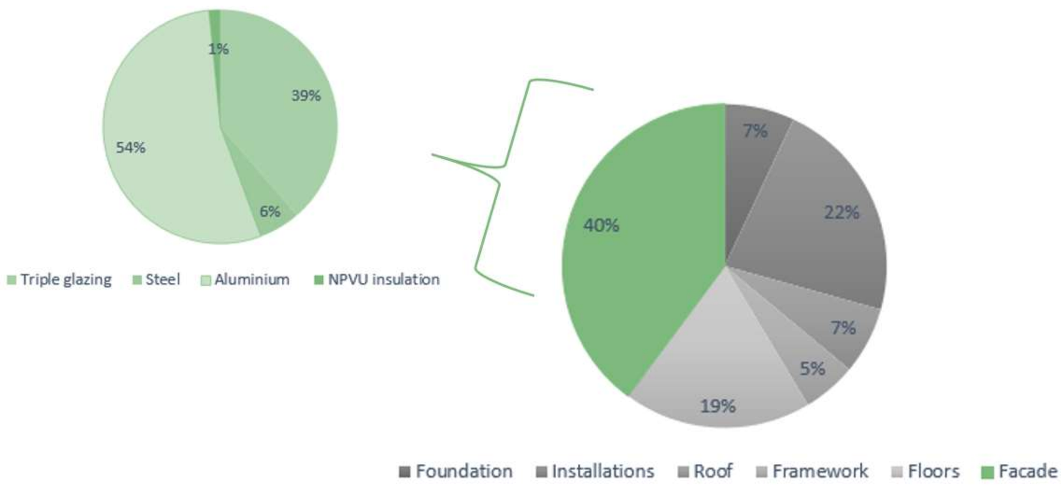


Figure 37: Distribution shadow costs reference office

4.4 DESCRIPTION VARIANTS

4.4.1 Overview variants

In this section the different variants that are calculated are described and assumptions made in these calculations are explained.

The goal of this case study is to give insight in the parameters in the facade design that have significant influence at building level in the total sustainability performance of the building and the total energy consumption. So the purpose is to expose the important aspects which can be further optimized in a more detailed study. In the variants, only design aspects that have to do with the facade are changed. So the installations, floors, foundations etc. all stay the same as in the basis variant.

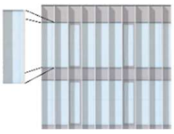
This way, a fair comparison can be made and the real impacts of the design aspects can be evaluated.

Genuinely facade systems are adjusted to the rest of the building, especially the structural system. In this research, the assumption is made that the structural system of the building stays the same even though the facade might be getting lighter/heavier in different variants. Only the structural system of the facade might change in some variants. In some variants, the facade will be heavier than the reference case; the material impact would be slightly underestimated than. This is not taken into account in this study. In the variants, a service life of 50 years is assumed.

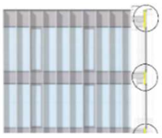
In table 6, the chosen variations are shortly explained and expectations are indicated. In the next section, the variants are explained in more detail.

Table 6: Overview variants

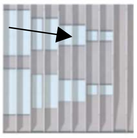
0.Reference
Basis situation of the reference building. This is the standard variant where other results will be compared with.



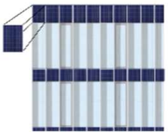
1.Glass
The influence of the different type of glazing used in the facade is analysed. Types of glazing that are examined are: Triple, HR++, HR+, HR, double and single. The expectation is, the thicker the layers, the more embodied energy so the higher the MPG and the lower the energy demand and this the EPG of the building. The decrease in EPG is expected to be higher than the increase in MPG and the less energy demand needed



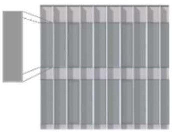
2.Insulation
R_C value: The difference in MPG and EPG is analysed when the R_c value of the facade changes. Next to the calculations for 80% open facade, this variant will be calculated with 20% open facade.
The insulation value is expected to influence the heating, and cooling demand, the change in R_c value in the variant with 20% open parts is expected to have more impact than the variant with 80% open parts.
Insulation material: The insulation material is varied with available materials from the database. This variant will also be calculated for 20% open parts. The expected difference is small.



3.Percentage open/closed
Calculating the influence of different ratios of open and closed parts in the facade. The percentage of open parts is varied from 0% to 100%. This variant is also analysed for different types of glazing and for HR++ and no louvres. It is expected that the more closed parts in the facade, the less energy is required and less embodied energy is used. Therefore the EPG and MPG will both decrease.



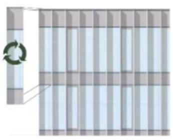
4.PV
In this variant different amounts of PV panels are added on the facade. This is done for different orientation and different amounts of area. An increase in MPG is expected and a decrease in EPG.



5.Sun shading
Different types of sun shading will be analysed in this variant. Per type, scenarios of automatically controlled, hand-controlled and permanent sun shading are examined. All variants are also considered without louvres. A better EPG is expected and a higher MPG in the variants with louvres.

6. Facade composition
Different facade packages: A different facade package with a wooden, concrete and facade of natural stone is calculated. In this variant, only the MPG will be varied.
Aluminium substituted: In this variant, the aluminium used for the louvres or facade will be substituted by different materials. Only when no louvres are applied the EPG will change, otherwise this variant is about the change in MPG.
Height:_ A change in the height of facade with a constant gross floor area is analysed for 10% and 20% increase or reduction of facade height.

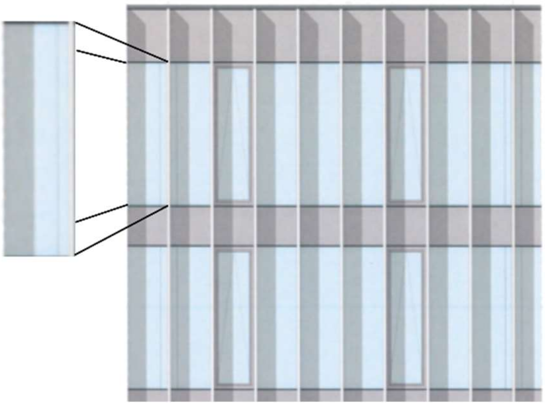
7. Orientation
The orientation of the reference building is changed in this variant. The orientation will only influence the EPG. The expected effect is small.



8.Service life/ Circular
In this variant, a change in service life for the whole building is calculated, only influencing the MPG. In a more detailed study, different scenarios of circular building are looked at. A significant reduction in MPG is expected.

4.4.2 Variant 1: Type of glazing

Conventional glazing systems



The type of glazing used in the reference office building is triple glazing with a total glass thickness of 16 mm. In this variant, the effect of changing the glazing system to triple glazing with a thickness of 12 mm, HR++, HR+, HR, double glazing and single glazing is shown. The open parts of the facade consist of a curtain wall system with aluminium vertical louvres on the outside. These louvres affect the solar heat gain coefficient (SHGC = ZTA in Dutch). For triple glazing, a normal SHGC of 0,55 is known (Lente akkoord, 2014). The SHGC of the glazing as in the energy performance calculation is 0,3. This difference of 0,25 caused by the louvres is assumed to be the difference for all types of glazing in the design with a curtain wall system with louvres. Next to the SHGC value, the U-value is essential input in this variant. The U-value is a measure for how effective a material is as an insulator. The lower the U-value, the better the insulation value. The U-value that has to be entered is the total U-value of the window. Following ISO 15099, the U-window can be derived using: (Feldmeier, 2000)

$$Uw = \frac{Ug * Ag + Uf * Af + \psi * l\psi}{Aw}$$

U_w	U-value of the window in W/(m^{2}K)
U_g	U-value of the glazing in W/(m^{2}K)
U_f	U-value of the frame in W/(m^{2}K)
A_w	area of the window in m^2
A_g	area of the glazing in m^2
A_f	area of the frame in m^2
lψ	perimeter length in m
ψ	linear thermal transmittance in W/(mK)

The area of the glazing is 2,49 m^2 (840 mm x 2960 mm), and the area of the window is 2,88 m^2 (960 mm x 3000 mm). This is determined based on the drawings. Important to take into account are the different U-values of the glazing and also of the frame. (Lente akkoord, 2014) Thermal bridges have more effect on single glazing systems and less in the case of triple glazing. With a better type of glazing also better frames are used. In this variant, it is assumed the psi factor is constant; however, in reality, this will differ per type of glass. The psi factor is about the loss of heat at the connection of the frame and glazing. (lψ=7,6; ψ=0,16) In table 7, the input for the glass variant is summed.

Table 7: Input glass variant

Glazing type	*U glass*	*U window*	*SHGC (g-value)*	*SHGC (without louvres)*
Triple glass (t= 16 mm) (Reference)	0,6	0,9	0,3	0,55
Triple glass (t= 12 mm)	0,7	0,98	0,3	0,55
HR++	1,2	1,36	0,35	0,6
HR+	1,6	1,47	0,35	0,6
HR	1,9	1,84	0,35	0,6
Double	2,8	2,90	0,52	0,77
Single	5,6	5,62	0,62	0,87

In this variant, only the U-value and SHGC value are varied. The lighting is kept constant. Also, the amount of incoming daylight stays the same, although this influences the energy performance of the building. To know the exact influence of this, a more detailed study can be performed. The results of this variant already will give a reasonable estimation of the magnitude of influence of the type of glazing.

Unconventional glazing systems

The influence of existing glazing systems such as triple glazing and HR++ will be significant and can change the energy performance as well as the environmental performance. With more layers of glass, energy will be saved but the embodied energy increases. When taking into account other factors next to the DPG and energy such as transport and costs, the results will show that the triple glazing with a thickness of 16 mm used in the existing building will probably not the most advantaged type of glass. Other types also have a low sustainability performances and less weight than triple glazing. There are more innovative solutions that can reach the same energy performance but have a lower environmental impact. These options will be looked into as well. Already a lot of research is done of new glazing systems, especially of the energy performance. For example, coatings are optimized as well as the thickness of glass layers and cavities. In this section, vacuum glazing and triple glass with a thin layer of glass as the middle layer are further looked into. These systems have, next to an excellent energy performance, also influence on the environmental impact, contrary to aforementioned examples like different coatings.

Vacuum glazing

The technique for vacuum glazing systems is known for some years already, but it is still not applied in office buildings, only in monumental buildings. Because it is not produced on a large scale yet, the costs of vacuum glazing are high. In 2018 Glass Europe decided to invest in the production of vacuum glazing. (Redactie Bouwwereld, 2018)

Vacuum glazing is double glazing of two sheets of glass of which one is covered with a super-insulating coating, separated from each other by a vacuum layer, see figure 38.

To keep the sheets separated, pillars are added in between the sheets. In this calculation, pillars made of steel are used having a diameter of 0,25 mm. The vacuum layer is assumed to be 0,25 mm.

Different pillar intervals can be chosen. The distance between the pillars is of influence for the U-value. The larger the interval, the smaller the U-value. In this variant, the largest available interval of 50 mm is chosen to have the lowest possible U-value.

Production
The production process must be known to estimate the energy use during production and the difference between conventional glazing systems. The necessary steps in the production of vacuum glazing are: (Kocer, 2012)

- Cut, drill holes in one pane, clean and prepare glass panes to assemble.
- Place an array of pillars on pane one and pair with the second pane,
- Apply soldier glass on the edge, place a glass tube in the hole with soldier glass on the base of the hole.
- Place in the oven, attach a pump head over the pump-out tube and bake at 450 – 480°C for at least 30 minutes.
- Cool to solidify the soldier glass and evacuate the gap.
- When the gap pressure is sufficiently low, the pump-out tube is sealed.
- Glazing is cooled, cleaned, tested and installed.

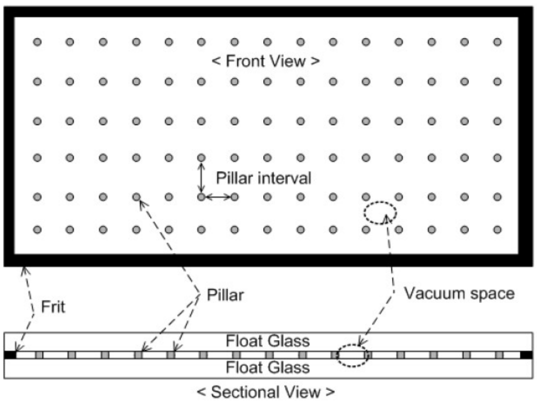


Figure 38: Drawing of vacuum glazing (Cho & Kim, 2017)

Input
In the energy calculation known values of vacuum glazing performances are used. For a system with panes of 5 mm and a vacuum layer of 0,25 mm a U-value can be obtained of 0,682 W/m²K, resulting in a total U_{window} of 0,97 W/m²K for this building. The g-value of 0,633 (0,383 with louvres) is higher than previous systems used, so more solar energy is gained with this glazing system. (Cho & Kim, 2017)

When a thickness of 3 mm is used, the U_{window} is increased to 1,42 and g-value is slightly increased to 0,43. (Fang, Trevor, & Hewitt, 2010) Also, the performance of a system with triple vacuum glazing is calculated. In this system with three panes of 4 mm, a U value of 0,28 is reached, resulting in a U_{window} of 0,58. All U-values and g-values used in this variant can be seen in table 8.

Adjacent to the type of glass, 6,33 kg of steel is included in the calculation of environmental performance of the building. (A pillar interval of 50 mm is used and a diameter of 0,5 mm.)

In the calculation of the environmental impact, conventional glazing systems are assumed. However, vacuum glazing can have a service life of 50 years. (Jianzheng, 2015) No LCA of the vacuum glazing system is known. Therefore the assumption is made that the environmental impact is similar to conventional insulation glass. However, the expected service life of vacuum glazing is 50 years, which is twice the service life of the conventional insulating glazing systems considered before. Therefore, it has the potential to cause less environmental impact as considered in this calculation. While the production energy of vacuum glazing will be more than the assumed values, the calculation will still be on the conservative side because of the service life. The most considerable difference in production is that the vacuum glazing is baked. Baking for 30 minutes on 450-480°C will use approximately 10,8 MJ/m^2. A high-temperature benchtop oven is used as a reference with a maximum power of 3000 W. (Carbolite, 2019) When comparing this to the share of embodied energy used for the HR++ glazing (MPG=0,16; Energy = 15,64 MJ/m^2*BVO*year), this is only around 1%. Therefore it can be neglected.

For the calculation of the single vacuum system, HR++ is assumed, also having two glass panes and coating. For the double vacuum glazing, triple glazing is assumed. Both the vacuum glazing and double vacuum glazing system is calculated with and without the louvres of the existing building, causing an increase in g-value of 0,25 and a decrease in the total environmental impact. The third calculated variant is without louvres and with automatically controlled sun shading.

Table 8: Input innovative glazing (Cho & Kim, 2017)

Glazing type	U_{glass}	U_{window}	SHGC	SHGC (without louvres)
Triple glass t=16 mm (Reference)	0,6	0,9	0,3	0,55
Vacuum glass (2x5mm)	0,682	0,97	0,383	0,633
Vacuum glass 2x3mm	1,2	1,42	0,43	0,68
Double vacuum	0,26	0,58	0,3	0,55
Triple glass incl. gorilla	0,6	0,9	0,3	0,55

Triple glazing with the middle layer of gorilla glass

Adjacent to the vacuum glazing, a variant composed of two normal outer layers of glass and one middle layer of gorilla glass is considered, see figure 39. Gorilla glass is a glass technology developed by Corning. It is thin glass and mostly used as a glass cover for smartphones, laptops or TVs. Gorilla Glass is chemically tempered. Corning uses Ion exchange to strengthen gorilla glass.

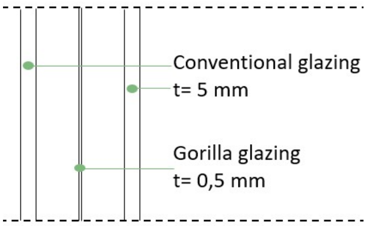


Figure 39: Cross-section of triple glazing with gorilla glazing in the middle

This process creates a compression layer on the surface on the glass and therefore, the glass is prestressed to increase the tension the glass can take. Gorilla Glass was first available in 2007, and at the moment the sixth generation is on the market. (Corning, 2019) It is called gorilla glass because it has the same characteristics as a gorilla, 'tough yet beautiful'.

No LCA or information about energy or impact of production is available of gorilla glass. However, the impact is expected to be higher than of conventional glass because more materials are used to produce Gorilla Glass compared to regular glass. (Earthsquad, 2019) Aluminium oxide is used for strengthening the material, and next to silica, sand, limestone and soda ash also magnesium and sodium ions are used. (Cheng, 2019)

In this variant gorilla glass of 0,5 mm is used with outer panes of 5 mm each, so a total thickness of 10,5 mm is obtained. The thermal properties are assumed to be equal to conventional triple glazing because the thickness of the middle layer has no significant impact on the insulation value or solar heat radiation.

In the calculation, it is assumed the production of gorilla glazing triple glass has the same environmental impact as conventional triple glazing. Some differences that can cause an increase or decrease in the environmental impact of the building are summed below.

Possible increase in impact or energy use because of:

- Energy is needed to prestress the gorilla glass.
- More transport is necessary because of the need and import of more materials needed for production.
- Other materials are used that are more of a burden for the environment (more metals).

Possible decrease in impact or energy use because of:

- The glazing is much thinner, and therefore, the other elements such as structural frame can be lighter as well.
- Therefore, also the energy use for transport decreases.

Costs of glazing types

To be able to say something about the financial feasibility, the costs of different types of glazing are summed in table 9.

Table 9: Costs of types of glazing (Milieucentraal, 2019)

Type of glass	€/m2
Single glass	65
Double glass	115
HR glass	120
HR+	125
HR ++	130
Triple glazing	170
Vacuum glazing	250
Triple vacuum	280
Triple with gorilla glass in the middle	300

Vacuum glazing is not applied often because of the costs. It is expected that the coming years the price will be lowered significantly. The glazing system is not produced on a large scale yet, through which producers encounter no competition. Glass Europe already is investing in vacuum glazing, and therefore this market is in development.

Energy savings

To give an overview of the payback time of different glazing systems the Net Present Value (NPV) is calculated in this section. With the NPV calculation, the payback time can be calculated.

The future value of money flow PV in year n is:

$$FVn = PV * (1 + r)^n$$

FV= Future Value
PV=Present Value
r= discount rate = 2%

Therefore, the present value of money flow FVn in year n is:

$$PV = FVn/(1+r)^n$$

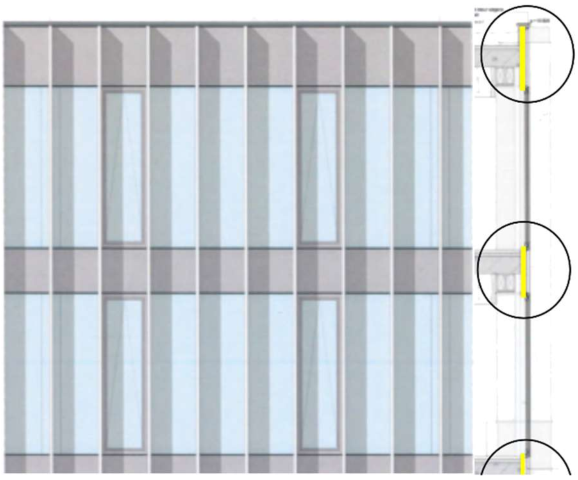
The net present value of the revenues and costs accumulated over n years is referred to as the Net Present Value (NPVn);

$$NPVn = \sum_{i=0,n} (PV_i) = \sum_{i=0,n} (FV_i/(1+r)^i) = \sum_{i=0,n} ((R-C)_i/(1+r)^i)$$

It is assumed the energy is gained from gas. The gas price is calculated using the new energy taxes and the energy price as stated by the Dutch Tax and Customs Administration and the climate agreement. (Belastingdienst, 2019)

In the calculation, all variants are calculated as what would be the influence by replacing the triple glazing by these innovative glazing systems. The calculation is also made for the conventional glazing types. Then the basic situation is the variant calculated, and the influence of replacing this by triple glazing is established. The results are described in 5.2.1.

4.4.3 Variant 2: Insulation closed parts facade



2a. Different Rc value closed parts

In this variant, the effect of different thicknesses of insulation is examined. In the reference case, the R_c value of the closed parts is 4,5 m^2K/W. In the building degree, this 4,5 is the minimum value for facades of new buildings. Smaller R_c -values are taken into account in this variant to see if this R_c -value of this 4,5 is necessary.

Table 10: Input variant Rc values

R_c (m^2K/W)	*Thickness insulation*
1,5	33 mm
2,5	55 mm
3,5	77 mm
4,5 (Reference)	99 mm
5,5	121 mm
6,5	143 mm
7,5	165 mm
8,5	187 mm
9,5	209 mm
10,5	231 mm

The differences in EPC and also energy demand between the two extremes (R_c=1,5 and R_c=10,5) might not be significant in this variant. Possibly because only 20% of the facade consists of closed parts. Therefore, the R_c value is also varied for the variant with 20% open parts. In this variant, more insulation is used, and a variation of the R_c value is expected to have more influence.

2.b Insulation material

NVPU-PU is the insulation material used in the reference building. A lot of new, bio-based, reusable, sustainable insulation materials are developed and on the market. NVPU-PU is not known as a sustainable material. In this variant, the difference between insulation materials is calculated. A selection is made of materials available in the database. The materials each have a different insulation capacity. It is assumed that the thickness in all scenarios is such that the R_c value is 4,5 m^2K/W. As a result, the thickness per material is different, as shown in table 11. In this variant, only the environmental performance changes, the energy performance stays the same.

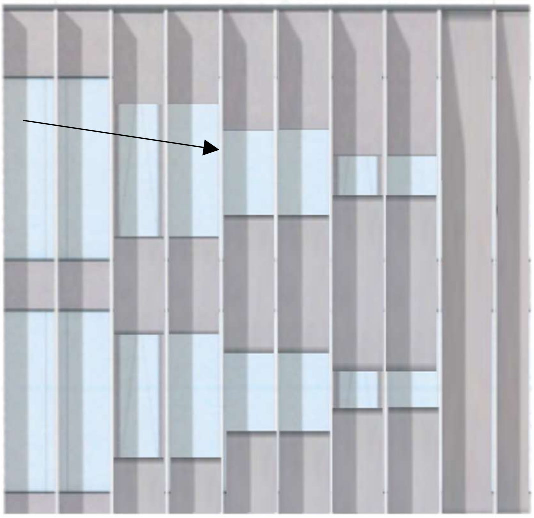
Table 11: Variant different insulation materials

	Lambda (W/m.K)	*Thickness (mm)*
NVPU PU (Reference)	0,022	99
Rockwool	0,032-0,041	144-185
Flax wool	0,038	171
Sheep wool	0,035-0,04	157-180
EPS panel	0,035	157
Woodfibre	0,04-0,08	180-360
Glass fibre	0,032-0,041	144-185
Aerated concrete	0,23	1035

Different insulation material with different ratio open/closed

This variant is also calculated for 20% open parts because of the same reason this was done in case of different R_c values. The insulation material is mainly for the closed parts of the facade, and when this is a small part of the facade, it is logical this has no significant impact at building level.

4.4.4 Variant 3: Change in ratio open/closed parts



As mentioned earlier, the facade of the reference building consists of 80% open parts. As known from the literature study, the percentage of open and closed parts has a large influence on both the energy performance and the environmental performance. In this variant the differences are calculated for 100%, 80%, 60%, 40%, 20% and 0% open parts in the facade. The extreme variants (100% and 0%) are not realistic in practice but are calculated to know the theoretical influence. The input for the energy performance calculation is shown in table 12.

The amount of materials used in these variants are calculated proportionally from the existing situation with 80% glazing, shown in table 13.

Because of the change in open and closed parts, not only the heating and cooling demand is changed because of a change in incoming sunlight but also the lighting is changed. The area of daylight is decreasing simultaneously with the percentage of closed parts in the facade.

Table 12: Input energy calculation variant open/closed parts facade: area of open parts in different facades

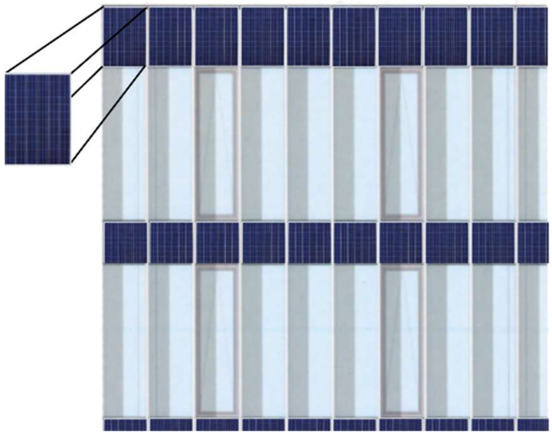
% open parts	*A_{Tot} (m^2)*	*N (m^2)*	*E (m^2)*	*S (m^2)*	*W (m^2)*	*A_{dayl} (m2)*
100%	2736	107	1260	114	1255	3125
80% (Ref.)	2185	0	1100	0	1100	2500
60%	1648	0	824	0	824	1875
40%	1100	0	550	0	550	1250
20%	550	0	275	0	275	625
0%	0	0	0	0	0	0

Table 13: Material input variant open/closed parts facade

% open	*Alu open*	*Triple Glazing*	*Alu closed*	*NVPU closed*	*NVPU open*	*Alu louvres*
100%	3228	3228	0	0	475	2815
80% (Ref.)	2582	2582	554	554	380	2252
60%	1937	1937	1108	1108	285	1689
40%	1291	1291	1662	1662	190	1126
20%	645,5	645,5	2216	2216	95	563
0%	0	0	2770	2770	0	0

3a. Combination open/closed parts and different glazing
The variant with a difference in open and closed parts is combined with different types of glazing. In the current situation, triple glazing is used, which is better insulating than other types of glazing but has more environmental impact compared to other types of glazing. Therefore, it is also interesting to combine this variant with different types of glazing. It is expected that the energy performance will decrease more, and the environmental performance will decrease a bit less.

4.4.5 Variant 4: PV panels on the facade



PV panels are the image of sustainability. Because of the known high environmental impact, it is questionable if PV panels are beneficial in terms of sustainability. There are already 538 m^2 of PV panels installed on the roof of the reference building. 184 m^2 of these panels are oriented east, 138 m^2 are oriented west, and 216 m^2 are oriented south. The slope of these panels is 10 degrees, and in total, they generate 774185 MJ per year. In this variant, the PV panels are included in the facade design to evaluate the consequences.

In all four orientations, an amount of 114 m^2 PV panels is included in the design. When the effect of orientation is known, the amount of PV panels can be multiplied. The variants are calculated with the amounts of PV panels as shown in table 14.

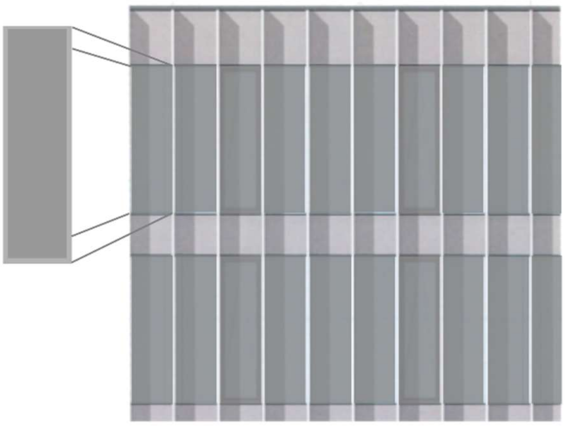
The type of PV panels chosen in the MPG calculation is multi-crystalline silicon. On the roof the PV version for flat roofs is used, on the facade, the version for pitched roofs is included because of a lack of facade PV systems in the database.

To give an idea of the costs in proportion to the yield in energy, an NPV (net present value) calculation is made in which the payback time of the PV panels is calculated to show the financial feasibility of the different scenarios.

Table 14: Amount of PV panels in the PV variant

Variant	*Amount of PV in m² and orientation*
Reference	0
1	114 N
2	114 O
3	114 S
4	114 W
5	114 O + 114 S
6	228 S
7	114 O + 228 S
8	228 O + 228 S

4.4.6 Variant 5: Sun shading



Sun shading can be beneficial for the energy performance of buildings. However, it is also extra material which results in more environmental impact. Therefore this variant is interesting, also in combination with other variants. Uniec2.2 has the option to mark if there is sun shading for every facade of the building. Two systems can be chosen, the auto and manual. Both of these systems are situations between no sun shading and permanent sun shading. Therefore also the ladder variants are calculated.

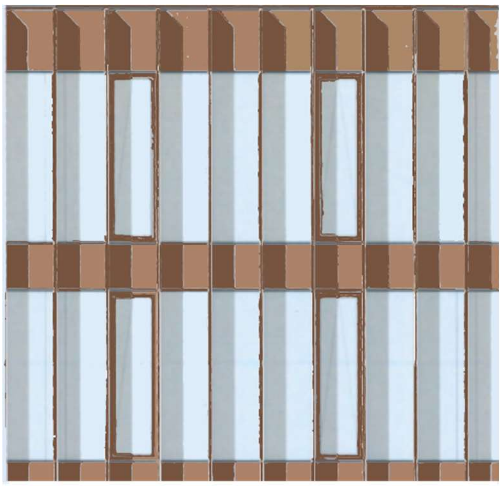
Next, the variants are also evaluated without the existing louvres. In these variants, the SGHC is higher than the one with louvres.

In this variant the performance of two types of sun shading is tested, roller blinds and a solid screen. Roller blinds are made of aluminium and can be automatically controlled, by hand or permanent be present. The frame of solar screens is also made of aluminium, and the screen can be of different materials, mostly from glass fibre with PVC. They can also be automatically or manually controlled. In table 15, the delta R and g-total of the systems can be read. The average of the lower bound and the upper bound is used in the calculation. The g-value is rounded below at a multiple of 0,05. So 0,05 is the lowest g-value possible, the model does not accept a value of 0,00.

Table 15: Variant solar blinds

Name	*Delta R*	*g-total*
Outside roller blinds +	0.16	0.01
Outside roller blinds -	0.13	0.05
Outside Solar screen +	0.18	0.07
Outside Solar screen -	0.14	0.05

4.4.7 Variant 6: Facade composition



6a. Different facade package

In this variants, the impact of a whole new facade package and composition is calculated.

The variants chosen are facade materials mostly used in office buildings in the Netherlands.

In the new variants, HR++ glazing is used. The insulating capacity of the closed parts is assumed to be 4,5 m^2K/W. In the calculation, a simple facade design is assumed with no louvres on the outside. Therefore the SGHC of standard HR++ glazing is used.

Wood

In this variant, wooden cladding is used with insulation and plasterboards. The frames are also made of wood. The assumption is made that the windows are 3m x 1,5 so the perimeter (in m) is twice the area of the window (in m^2). The structure behind the wooden panels is also of wood, and this is included in the panels in the database. The steel structure behind the facade is assumed to stay the same. In table 16, the amount of materials is shown. A European softwood cladding is chosen with a thickness of 18 mm, see figure 40.

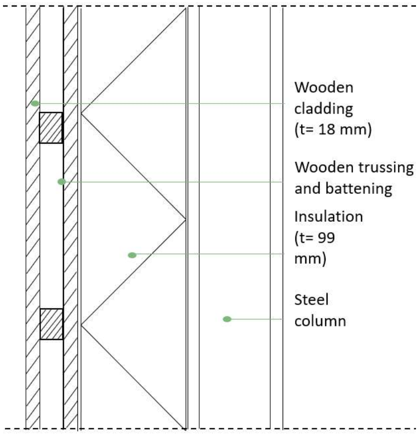


Figure 40: Simplification section wooden facade

Table 16: Variant wooden facade

% open parts	*Wooden cladding*	*NVPU PU*	*Glass HR++*	*Wooden frame*
100%	0	0	3104	6208
80% (Ref.)	621	621	2483	4966
60%	1242	1242	1863	3725
40%	1863	1863	1242	2483
20%	2483	2483	621	1242
0%	3104	3104	0	0

Natural stone

In this variant natural stone is used as cladding with a cavity and plasterboard, see figure 41. The thickness of the stone is assumed to be 8 mm. In this variant, the existing steel structure stays the same. In table 17 the input used in the calculation is shown.

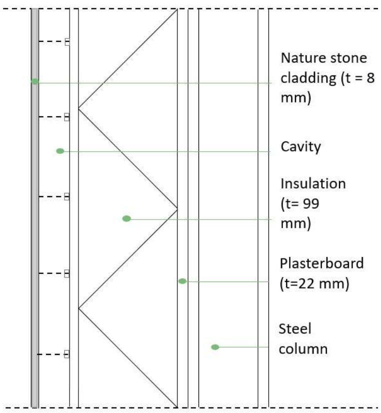


Figure 41: Simplification section natural stone facade

Table 17: Variant natural stone facade

% open parts	*Natural Stone*	*Insulation*	*Plaster*	*Glass HR++*	*Wooden frame*
100%	0	0	0	3104	6208
80% (Ref.)	621	621	621	2483	4966
60%	1242	1242	1242	1863	3725
40%	1863	1863	1863	1242	2483
20%	2483	2483	2483	621	1242
0%	3104	3104	3104	0	0

Concrete

Concrete is used in most Dutch buildings. Unfortunately, concrete has a large environmental impact, and a lot of mass is needed which also causes more transportation costs. In this variant, the difference of concrete with the other facade designs is estimated. The concrete walls are also assumed to be load-bearing. Therefore, the steel structure, as used in the reference case, is replaced, see figure 42. Because there is also a variant with 0% closed parts, a concrete structure with beams and columns is attached. The beams are 500x400 mm and the columns 350x350 mm. In total an amount of 280 m^2 of beams is used and 317 m^2 of columns. The input for this variant is shown in table 18.

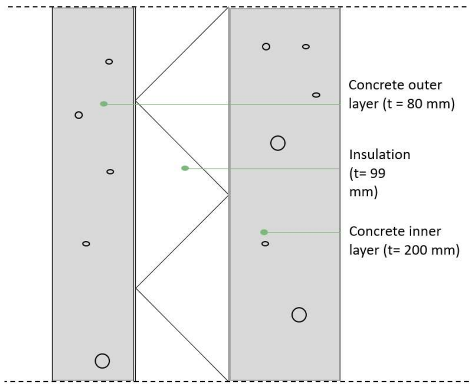


Figure 42: Simplification section concrete facade

Table 18: Variant concrete facade

% open parts	*Concrete*	*Insulation Rc=4,5*	*Glass HR++*	*Frame*
100%	0	0	3104	6208
80% (Ref.)	621	621	2483	4966
60%	1242	1242	1863	3725
40%	1863	1863	1242	2483
20%	2483	2483	621	1242
0%	3104	3104	0	0

6b. Aluminium louvres and facade panels substituted

The aluminium in the facade is responsible for the largest share in environmental impact. A large part of this aluminium is used for the louvres. Therefore, variants with a different material for the louvres are evaluated. Also, an analysis is done of a variant without louvres. Materials that are chosen are wood, natural stone and fibre cement. These materials have different characteristics and strengths, so, therefore, a different amount of material is used. The existing aluminium louvres are 1,3 mm thick. The chosen wooden louvres are made of Western Red Cedar, which is available in the database. In this element, the steel structure behind the louvres is also taken into account. For natural stone, a thickness of 5 mm is used and for the concrete variant a thickness of 3 mm.

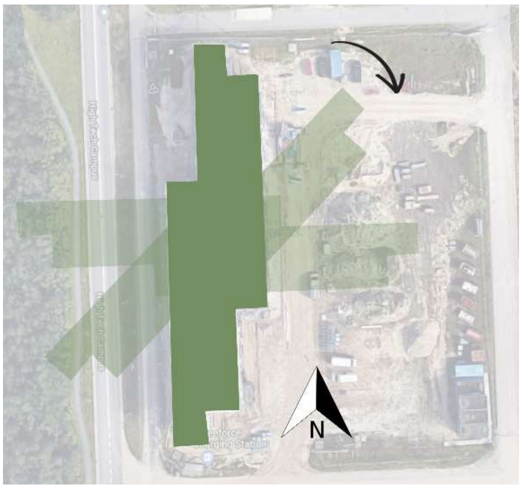
6c. Height of facade

In this variant, the influence of facade height is shown. The facade area is increased by 10% and 20% and decreased by 10% and 20%. The amount of materials in the facade is also decreased or increased by 10% and 20% in the MPG calculation. In the literature study, it already became clear the height of the facade has influence, and in this variant, the magnitude is determined. In table 19, the input is shown in m^2 materials and area.

Table 19: Amount of materials used in variant height of the facade in m^2

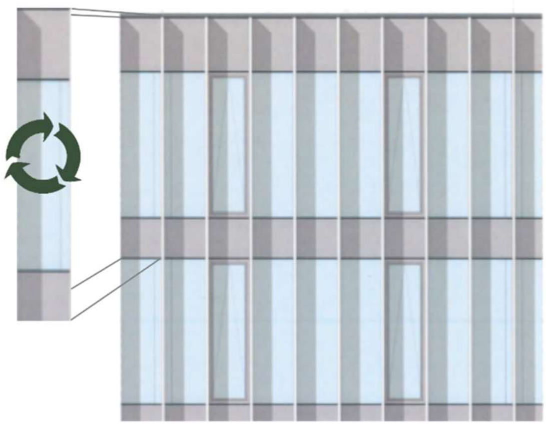
	Ref.	*+10%*	*+20%*	*-10%*	*-20%*
N & S facade	114	125	127	103	91
E & W	1260	1386	1512	1134	1008
Glass E&W	1085	1194	1302	977	868
Alu, open	2582	2840	2324	3098	2066
Glass	2582	2840	2324	3098	2066
Alu, closed	554	499	665	443	499
Alu, lam	2252	2477	2027	2702	1802
Insulation	934	1027	841	1121	747

4.4.8 Variant 7: Orientation



The building is oriented in such a way the closed facades are the north and south facades, and the curtain wall facades are oriented east and west. In this variant, the influence of orientation is explored by shifting the building over 45 degrees, 90 degrees and 180 degrees. The use of extra materials because of possible changes in the design, due to the surroundings and comfort such as doors or sun shading, are disregarded.

4.4.9 Variant 8: Circular variant



Service life of the building

The service life of the building has a relation with the MPG of the building. Some materials are already replaced within the service life, so; therefore, the magnitude of influence is not precisely known and is different per building and used materials.

In this variant, a service life of 25, 75, 100, 125 and 150 years is compared to the existing situation having a service life of 50 years.

Circular building

In the analysis of the MPG, it became clear the impact of the facade is mostly determined by the glazing system and aluminium in the facade. Together these elements are 93% of the whole environmental impact of the facade. The facade has a higher share in MPG compared to the average office building, so it is expected that the impact of the reference building can be optimised a lot.

One option to reduce the impact of materials used is a change of design or change in more sustainable materials. The impact when using other materials in the facade appeared to be small, and another design is probably not desirable by the architect or client. Therefore, different approaches should be explored to improve the environmental impact of the facade.

In this variant, the impact when using materials of the facade in a way corresponding to the circular building approach is evaluated. Different scenarios are considered namely service life extension and reuse of materials. The materials can be reused in the same building or get a new life in another building. With the latter option, the energy to demount and transport the elements need to be taken into account as well.

The goal is to minimise the total environmental impact. This can be done by increasing the service life either of a product or the whole building. Therefore, the quality needs to be improved. The problem is that nowadays the demand and requirements of buildings and offices change relatively fast. A substantial risk arises that the quality is still high, but the building does not meet the requirements in terms of aesthetics, function or technique anymore, and the building is shut down. Then too much quality and thus energy and materials are added in the beginning. Another option is to reuse more materials. To achieve this, the initial design should allow either more adaptability or demount ability. Most likely, these options will result in an initial increase in design, so it is essential to assure the design of elements and materials can in the future fulfil the demand.

Next, to the extra material added in the beginning, it is important to take into account extra transport and maintenance. Some parameters are hard to predict beforehand, and therefore, assumptions need to be made. In the databases, transport and maintenance are also assumed to be of a certain amount while this is also different in reality.

In this variant, the dilemma stays whether it is better to increase the impact in the building stage (by adding more material but improve the quality such that it will last longer) or to decrease the amount of material (and to know that the service life of the building or product will be shorter). The reason that it is not as easily answered is because of the insecureness of the demand and supply in the future. The building industry adapts slowly in comparison to other industries.

The most important options to reduce the environmental impact of the facade and mainly the curtain wall (and to keep the energy performance constant) is re-use of the elements and thus increase the service life or reduce the amount of material and thus design the facade more light.

The service life can only be increased when the requirements are met for the following aspects:

- Aesthetical: There is no demand for second hand (looking) products. Therefore it is important the products have the appearance of high-quality products. For this curtain wall, the colour and cornice must be maintained.
- Measurements: For reuse, it is essential to use standard measurements, then elements can be used in the same condition as the previous building. A flexible layout is also important.
- Performances: Requirements of the performances such as energy and environmental performance but also others keep changing. When a design can easily be changed and upgraded, it can also adapt to changing performance requirements and therefore the service life will be longer.

To evaluate different options and know the influence of variants, the scenarios, summed in table 20, will be evaluated in the following part of the research. In figure 43, a timeline of the different variants is shown.

Table 20: Overview scenarios circular variant

	Service life	*% Re-use*	*Service life class*	*% more material*
Scenario 1 (Reference)	50	0,1%	4	0
Scenario 2	20	0,1%	4	0
Scenario 3	20	60%	3	-10%
Scenario 4	100	0,1%	5	+10%

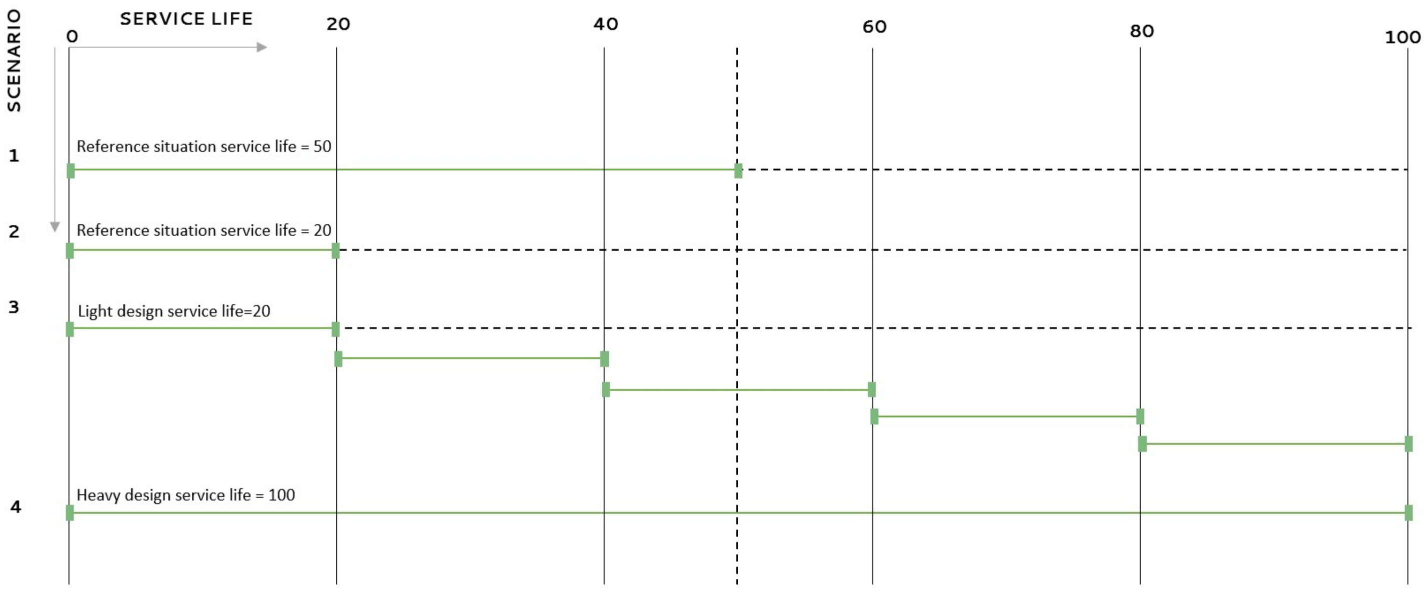


Figure 43: Timeline circular scenario's

Scenario 1: Reference design

The current situation as calculated has a service life of 50 years. 50 years is the standard service life for utility buildings. So the design is focused on those 50 years. The materials are the same as the reference case.

Scenario 2: Reference design with shorter service life

This scenario calculated the current situation with a realistic service life of 20 years. Unfortunately, the service life as used in the design of 50 years is commonly not realized. The average service life of office buildings is 20 years. The service life is ended when the building doesn't fulfil one of the performance requirements anymore. This can be functional, technical, aesthetical or economical. In this scenario, the realistic sustainability performance is calculated. Of the four considered scenarios, this will be the most unfavourable option. The used materials are the same as in the reference building; only the service life of these materials is shortened.

With a service life of 40% of the environmental performance is expected to be around 2 to 2,5 times higher than the reference situation. It will be less than 2,5 times because some elements will also be replaced within the service life of 50 years.

The information that the average service life of office building is only 20 years is not new. Architect Jouke Post designed 'Project XX', an office building built in 1999 with the goal to design and use the building for 20 years. According to Post circular building is nothing new; first, it was called building with limited service life, than cradle-to-cradle and now circular. (Wassink, 2019) His building has always served as an example. Although temporarily building has improved, the overall concept is still not understood. When not designing for infinity the project includes responsibility for the end of a building, deconstruction and residual value of the materials. (Klomp & Post, 1999)

Scenario 3: Reduce and reuse (new design focused on reuse and short service life)

In this variant, the service life is 20 years as in scenario 2, but the design of the facade will be adjusted to this new service life of 20 years. Therefore the design is focussed on reuse and a short service life, see figure 44. When the office is designed for only 20 years, it is more a temporary building and the service life will belong to design class 3 instead of 4. (NEN-EN 1990+A1+A1/C2, 2011) Less material will be needed because lower safety factors can be applied. The design will also be focussed on a higher percentage of reuse. Therefore the elements must be easily demountable or designed in another way reuse is made possible. In this variant, assumptions will be made about the amount of material that can be reused and the adjustments in the design and the maintenance needed to achieve this goal. To make a correct estimation, the material profiles of nibe.com are used, see appendix A. Furthermore, data will be used provided by suppliers such as Kawneer.

The most used materials in the facade are aluminium, glass, steel and NVPU insulation. The service life of the glass panels is around 25 years. It is hard to reuse glass, but it can be recycled for almost 100%. The service life of steel is 100 years and can thus be reused about 5 times. The service life of aluminium is 75 years. Currently, it is not reused a lot, but there is a high potential to reuse it.

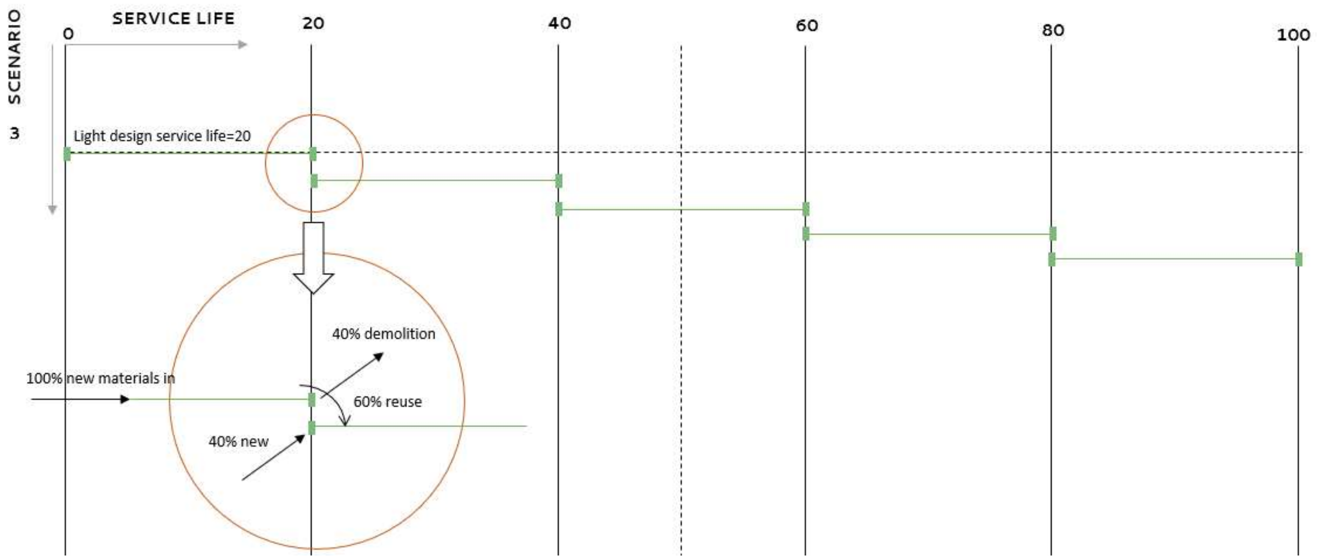


Figure 44: Timeline scenario 3

Significant aspects of being able to reuse elements and to reduce material use:

- The measurements need to be universal, the element size of the aluminium profile is 7,2 m, which is already a standard measurement.
- The facade must be demountable, so only dry connections need to be used. The curtain wall facade system now has a horizontal kit. This has to be replaced by a dry connection.
- Maintenance and preserving the quality is essential to be able to preserve the quality. The product should be as new when used for the second or third time in another facade.
- The aluminium needs to be anodised instead of coated.

Differences in the life cycle of products in this scenario:

1. Design: Lighter design (-10%)
2. Transport: Depending on the location of the building where the elements are reused there is slightly more transport. The transport is only 0,1 % of the environmental impact and can there be neglected. (Nibe, 2019)
3. Maintenance: In the environmental impact profile, 3,6% of the emissions are due to restorations. The amount of restorations is expected to be less than the reference situation. However, maintenance will be done after every 20 years, and with more transport, the change of damage of elements is larger, so the energy for restorations is taken into account in this scenario as well.
4. Construction: Extra energy is needed to construct the element after 20 years. This is 0,6% of the emissions and can also be neglected in the calculation. (Nibe, 2019)

The reuse of aluminium profiles in this calculated is assumed to be 90%. The steel element can be reused for 95%, and the glass is not reused. In total 62,2% of the weight is reused, see table 21. In this variant, no decrease in material reuse is assumed within 100 years. The service life of the aluminium elements is 75 years. In this scenario, 90% of this material will last 100 years. This assumption can be made because the current calculation of service life is conservative and in this scenario will be maintained more consistently. Therefore the quality will be better maintained, and the service life of the elements can be increased. The assumption can be made because the elements do not fulfil an important function in the structural frame of the building. The lifespan can be seen as five times 20 years instead of one long lifespan of 100 years. After 20 years, the quality of the elements can be as if they are new.

Table 21: Reuse of facade elements

Product	*Weight (kg)*	*Reuse (%)*
Triple glazing	103280	0
Aluminium profile curtain facade	11619	90
Aluminium facade panels	2216	90
Aluminium louvres	16214	90
Steel	176730	95
Total	313494	62

In this scenario, 10% less material is used in the initial design, which follows from a calculation of wind loads on the facade (see appendix E). The amount of glazing can be reduced by 15%. The safety factors have a direct influence on the wind load and weight of the glass. The amount of aluminium can be reduced by 10% because the depth of the profiles is not proportional to the stiffness of the profile.

Different approaches to calculate the MPG in scenario 3

Because it is not a standard situation, and some elements are being reused after the service life, a different calculation approach is necessary. In the databases, reuse is not taken into account, and therefore, the environmental performance will be different. Various methods are tried to approach a realistic impact. The hypotheses is that the score will be (0,403 + 0,121 + 0,732) 1,25, see figure 45. However, in this calculation, it is assumed that all materials have the same environmental impact. The high percentage of reuse is mostly because of 80% of the aluminium will be reused. Aluminium has the largest impact. Therefore the MPG could be slightly lower. Also, the MPG for 20 years for the parts that are not reused will not be times 2,5. This because the largest part of these materials is glass. The service life of glass is 25 years, so in the calculation of 50 years, the glass will also be reused 2 times. Therefore the actual difference in the glass will be 5 years, which is 20% of the total service life of 25 years. Therefore this part will be more around 0,19 (0,4*1,2*0,448*0,9) Then the total MPG will be 1,043, which is an improvement of 7%.

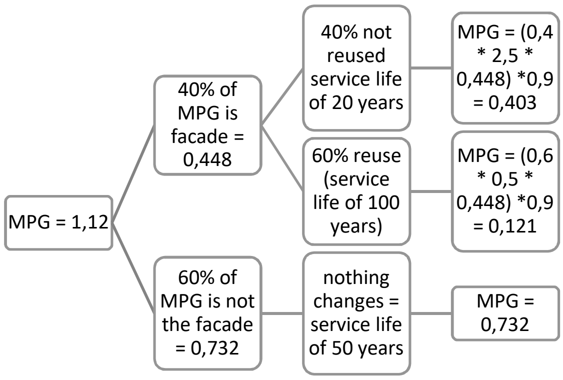


Figure 45: Calculation distribution of MPG

Different approaches are used to calculate the environmental impact with the help of the MRPI-MPG tool. The difference in a multicycles analysis is compared to a single cycle analysis. Lastly, a scenario is compared in which the elements turn out to be not suitable for reuse after the service life of 20 years.

3a. Multicycle

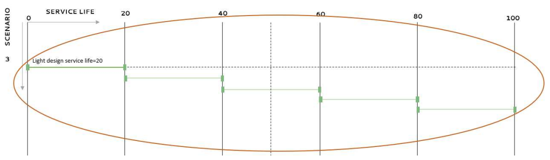


Figure 46: Multicycle considered scope

In 100 years the cycle will be run through 5 times. Therefore 300% of the material used for the facade is added in total because, after each cycle, 60% is reused except for the last cycle. In the first cycle, 100% new material is added and in the other cycles 40%, see figure 44.

1. The first calculation is done with a service life of 20 years and material use of 60%. This results in a total DPG of 1,98.
2. In the second calculation of the multicycle analysis, a service life of 100 years is combined with a material use of 300%, resulting in a DPG of 1,54.
3. Both previous options are not accurate because the service life of the whole building is changed instead of only the facade. Therefore, in the calculation of 20 years, the impact becomes much higher than realistic. In the calculation of 100 years, the transport, construction and composing of elements in between the 20 years are not taken into account. Therefore a combined approach is used in which three calculations of the environmental impact are summed. The three calculations with different service lives are:
    1. 50 years (whole building minus facade elements)
    2. 20 years (elements that are not reused)
    3. 100 years (reused elements)

3b. One cycle of 20 years

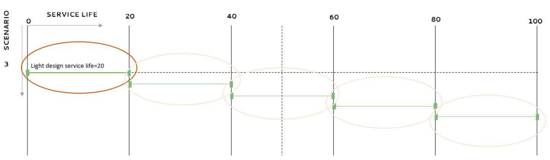


Figure 47: Single cycle considered scope

The second approach of this variant is highlighting one cycle of 20 years. The amount of new materials is 100% at the start, but 60% is reused at the end of the 20 years to a reduction of 60% is given to the environmental performance. Again, different calculations are compared:

1. The service life is 20 years and material use of the facade is reduced by 40%. The DPG in this variant is comparable with 3a.1 but with 1,91 slightly lower.
2. In the second calculation, 40% of the impact of 3c is taken. This results in a DPG of 1,01.

3c. Designed for reuse, but not reused in the end, unforeseen end of service life after 20 years

Figure 48: Reduction service life considered scope

The environmental impact for this scenario is calculated with a service life of 20 years and material use of 100%, resulting in a DPG of 2,22.

The combined approach of 3a.3 seems to be the most realistic approach and thus will be used and analysed in section 5.2.

Scenario 4: More quality and adaptability (new design focussed on the extension of service life)

In this scenario, the same building is designed for a facade with a service life of 100 years. Therefore more material is needed because safety factors are increased, and higher quality is required. The percentage of reuse is similar to the reference case. Materials and elements of the facade must either be of such high quality that it can be sustained for 100 years, or the design should be adjustable so that it can fulfil the requirements with small interventions. With the changing requirements, it is more realistic to make the facade adaptable for changing requirements. So when an extra layer of glazing is required, the aluminium profile must be large enough that an additional panel of glass can be included. This corresponds to the design for change strategy. (Circular facades, 2019)

The environmental performance in this scenario is composed of different parts, as in scenario 3. The first part of the calculation, with a service life of 50 years is the same as in scenario 3. The second part is the environmental performance of the facade with a service life of 100 years.

Different levels of adaptive ability can be distinguished:

- Layout
- Allocation
- Building volume

The reason for the vacancy and demolition of office buildings is often the lack of energy performance and quality of building physics, which is important for the comfort of the building. Due to fast changes in ownership of offices, also the flexibility of the building because changes in function are required is often a problem. Therefore, also the layout in the building is crucial. In offices, the change of vacancies and demolition is greater than for residential buildings because more decision moments exist. (PBL, 2019)

Because of the increase in service life the design service life class is changed from 4 the reference situation to 5.

Aspects of the facade that need to be changed:

- Use of anodised aluminium instead of coated aluminium because the recycling process can be executed better. Manufacturers prefer anodised product because when recycling coated products, a particular contamination arises in the melting process. This reduces the quality of the recycled product. This is not the case with anodised aluminium.
- The aluminium profiles should be designed with a larger width to make it possible to add more insulation, glass or other elements.
- All connections need to be demountable to replace elements that would not fulfil the requirements anymore.
- The structural frame of the building must be over-dimensioned to be able to add weight during the lifetime of the building. For example, more layers of glass can be added, PV panels or a green facade.

Differences in the life cycle of products in this scenario:

1. Design: Heavier design (+10%)
2. Transport: Transport is similar to the reference case, only more material has to be transported initially.
3. Maintenance: The maintenance is expected to be more than the reference situation because, in 100 years, the requirements change and the building need adjustments to fulfil the requirements still. However, maintenance can be easier because the building is designed to be easily adjusted.
4. Construction: The construction is comparable to the reference design. In the service life, the building is constructed once and demolished once.

5. RESULTS CASE STUDY

In this chapter, the results of different variants are showed and interpreted. Results are evaluated based on different aspects. First, the sustainability performance, which is a summation of the energy performance (EPG) and environmental performance of buildings (MPG), is looked at. Secondly, the total energy use of the scenario is evaluated which includes the embodied energy of the materials and the energy demand of the building. The total energy demand is determined by the sum of energy used for heating, cooling, hot tap water, fans and lighting. The results are based on standard energy calculations and the existing database. At last, the total CO_2 emissions are appointed. The results are interpreted, taking into account several assumptions made in the models to avoid assuming incorrect relations.

5.1 RESULTS OF VARIANTS

5.1.1 Variant 1: Type of glazing

Conventional type of glazing

Sustainability performance

Triple glazing made of 3 panels consisting in a total thickness of 16 mm glass has the lowest score in EPG. The EPG will increase when less insulating glass is applied. Therefore also the energy demand is increasing. The total energy use, when applying single glass, is 59% more compared to triple glazing, see table 23. This is mostly due to an increase in the heating demand. In the energy performance results, the only components that are subjected to change are the cooling and the heating. The heating demand has a substantial increase, and the cooling demand stays within a smaller range of 2,5*10^3 MJ, see figure 49.

When the type of glass is different, the important parameters being changed are the U-value and g-value. When the g-value decreases less sunlight is incoming, and the heating demand increases. Logically, the cooling demand decreases. When the U-value is increasing, and the g-value is constant, which is the case when comparing HR++ to HR+ and HR glazing, the same amount of sunlight will enter the building. However, the heat gets out easier, and therefore the, cooling demand is less. Then the heating demand is increasing, see table 22.

Table 22: Relation U- and g- value to heating and cooling demand

	Heating demand	*Cooling demand*
Increase in g-value	-	+
Increase in U-value	+	-

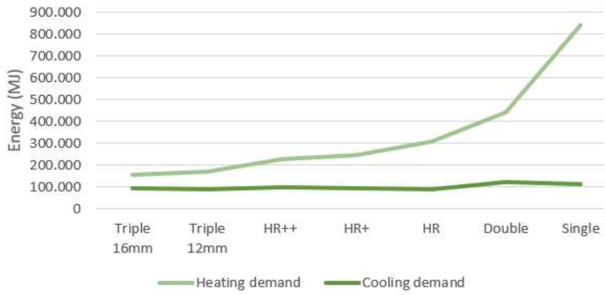


Figure 49: Heating and cooling demand for different types of glazing

The environmental performance is decreasing when using less glass. Fewer materials are needed, and therefore, less energy is used for transport and production. The embodied energy decreases with 14% when comparing triple glazing to single glazing.

With less insulating glazing systems, the sustainability performance is increasing. This because the energy performance is much worse with double and single glazing. HR++ glazing only has a DPG less than 1% worse than triple glazing. Therefore it cannot be easily concluded that triple glazing (t= 16 mm, the design used in the reference building) is better than HR++. This because the DPG is almost the same, and other effects that are not taken into account may play a role in this study. For example triple glazing cost more, weights more (so a heavier structure is needed, more labour costs, etc.). This is further elaborated in the discussion. Other parameters that will be influenced by a different type of glazing are not taken into account in this study.

The triple glazing with a total glass thickness of 12 mm has the lowest total sustainability score because of a significant improvement in the MPG and a hardly noticeable decrease in EPG, see figure 50.

One remarkable result of the glazing variant is the MPG of triple glazing with a thickness of 12 mm (1,07), compared to the MPG of HR++ (1,08) which has a total thickness of 10 mm. Probably no coating is included in the triple glazing. Because a higher value of MPG is expected, therefore the MPG of the triple glazing calculated might be underestimated.

Table 23: Results variant glazing

	DPG (€/m^2)	*Total energy (MJ)*
Triple t=16mm (Reference)	1,32	1.664.575
Triple t=12mm	1,27 (-3%)	1.649.826
HR++	1,33 (+0,5%)	1.706.581
HR+	1,34 (+1,5%)	1.722.099
HR	1,36 (+3%)	1.772.691
Double	1,47 (+12%)	1.949.603
Single	1,68 (+27%)	2.287.498

Total energy use

The total energy increases when using less glass, see figure 50. This is because the increase in the energy demand of the building is more than the decrease in the embodied energy of the materials.

CO_2 emission

The increase in DPG is mainly due to the increase in CO_2 in the EPG. Therefore also the percentage of CO_2 in the contribution to DPG is increasing from 52% to 67%.

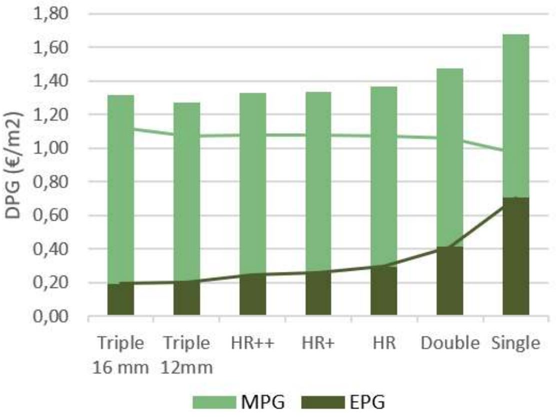


Figure 50: EPG and MPG of glazing type (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

Vacuum glazing

For all three types of vacuum glazing that are looked into the same variation in the three subvariants can be seen, see figure 51 and table 24. The subvariant with vacuum glazing and without louvres has the lowest DPG score, and all three subvariants improve from 4% to 7%. The CO_2 emission is the lowest in the version without louvres and including sun shading.

The energy performance of the first variant of vacuum glazing (2x5 mm) is almost as good as triple glazing, without louvres and with sun shading the energy performance is even better. The MPG is 4% improved compared with triple glazing, and therefore the total DPG has improved with 3%. The variant without louvres is improved with 5% and the variant without louvres and with sun shading with 4%. However, this latter variant has an improved total energy use of 5%, and the variant without louvres does not. The total CO_2 emission in all three options is less than the reference situation and the lowest when no louvres or sun shading is used.

The second variant of vacuum glazing (2x3 mm) has a higher energy performance of 0,05 compared to the first one. The MPG of this variant us 0,07 lower thus in total the DPG score is better than the previous version, also without louvres and with sun shading.

The third variant considered double vacuum glazing (3x4 mm). The total DPG is slightly lower than the second variant, but the sun shading and version without louvres do not score better than 2x3mm glazing. Comparing the 3x4mm with the 2x3mm, the impact for the added material is about the same as the reduced emission by a lower energy demand. When changing only the glazing type, this is slightly in favour of 3x4mm, and when also removing the louvres, the 2x3mm version is in favour.

Gorilla glazing

The DPG of the triple glazing with gorilla glass in the middle has for all three variants positive results. As well as the sustainability performance, the total energy demand decreases. The most improvement is achieved with the gorilla glazing without louvres and with sun shading. The total CO_2 emission in this variant is also the smallest.

Table 24: Results from innovative types of glazing

	DPG (€/m²)	*Total energy (MJ)*
Triple t=16 mm (Reference)	1,32	1.664.575
Triple t=12 mm	1,27 (-3%)	1.649.826
Vacuum 2x5mm	1,28 (-3%)	1.706.581
Without louvres	1,26 (-5%)	1.668.425
Incl. sunshades	1,27 (-4%)	1.573.463
Vacuum 2x3mm	1,26 (-5%)	1.692.356
Without louvres	1,23 (-7%)	1.702.498
Incl. sunshades	1,23 (-7%)	1.596.912
Double vacuum 3x4mm	1,25 (-6%)	1.596.080
Without louvres	1,24 (-6%)	1.637.417
Incl. sunshades	1,26 (-4%)	1.548.342
Gorilla triple	1,26 (-5%)	1.628.923
Without louvres	1,24 (-6%)	1.652.613
Incl. sunshaded	1,26 (-5%)	1.567.057

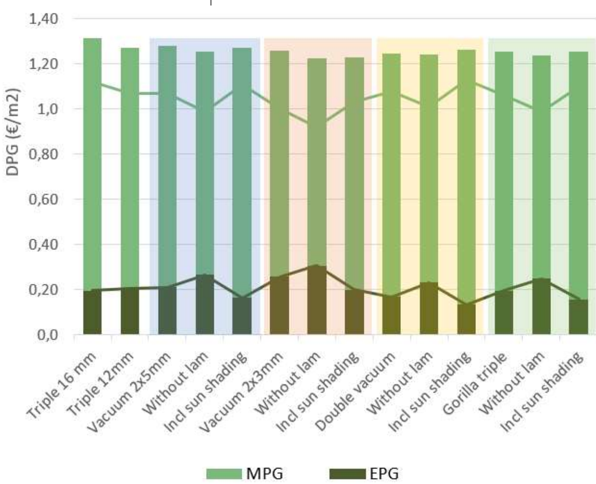


Figure 51: EPG and MPG innovative glazing types (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately) ■ represents vacuum glazing of 2x5 mm, ■ represents vacuum glazing of 2x3mm ■ shows variants double vacuum glazing of 3x4mm and in ■ the results triple glazing with gorilla glazing in the middle can be seen.

NPV calculation

Although the sustainability performance is improved when using vacuum glazing, the energy demand is more than triple glazing, and the costs of the glazing are also more. Therefore vacuum glazing will not be financially profitable. The same holds for the triple glazing with gorilla glazing in the middle. The energy performance is not improving, and the costs are increasing. The triple vacuum has an improved energy performance but not enough to compensate for the extra costs of the triple vacuum glazing.

For the conventional glazing, having triple glazing is only financially profitable when replacing it from single or double glazing. The payback time of triple glazing from HR glazing is 45 years, and when the glazing would be HR+, HR++ or triple glazing with a thickness of 12 mm, it is way more than 50 years. The results of the calculation can be seen in appendix G.

5.1.2 Variant 2: Insulation closed parts facade

2a. Different RC value closed parts

Sustainability performance

As expected with the knowledge of the study about the influence of insulation thickness in 3.4, a difference in Rc value almost does not influence the EPG. The heating demand is slightly decreased (6%) by an increase of Rc value from 1,5 m^2K/W to 10,5 m^2K/W, and the cooling demand is only increased by 0,1% The total EPC is increased by 3% considering an Rc value of 1,5 m^2K/W and decreased by 1% considering an Rc value of 10,5 m^2K/W.

The increase in environmental impact for adding material to insulate the building is unnoticeable in the MPG score. It causes a small increase, but this is not significant at building level.

The sustainability performance is changed in all scenarios by less than 1%, see figure 52 and table 25. The reduced emissions by adding insulation are compensated by the emissions released by production.

To better understand the influence of the Rc value, this variant is also calculated with 20% open parts instead of 80%. These variants score better on the sustainability performance because of more glass results in both an increase of MPG and EPG. Contrary to what was be expected, differences between different Rc values also stay small in this variant. There is a bit more difference visible than in the variant with 80% open parts in the facade. The total DPG is lowest for an Rc of 4,5 m^2K/W and an Rc of 9,5 m^2K/W. The differences are minimal, and therefore it can be concluded that the Rc value has no significant impact at building level when the same glazing system is used, also with a large share of closed parts in the facade.

Table 25: Results variant insulation value

Rc in m^2K/W	*DPG (€/m^2)*	*Total energy (MJ)*
1,5	1,32	1.668.925
2,5	1,318	1.665.093
3,5	1,317	1.663.818
4,5 (Reference)	1,316	1.663.383
5,5	1,315	1.663.340
6,5	1,315	1.663.534
7,5	1,315	1.664.120
8,5	1,315	1.664.523
9,5	1,315	1.665.107
10,5	1,324	1.665.719

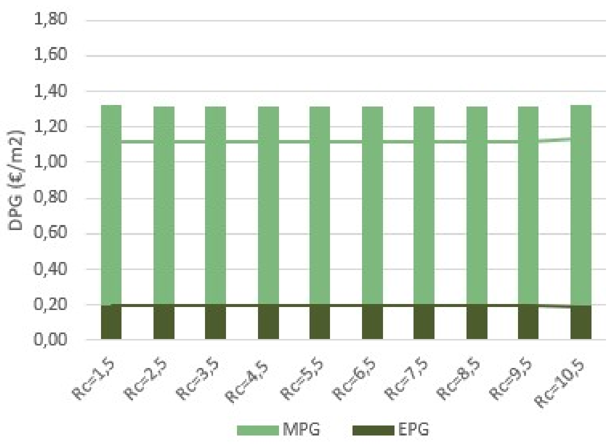


Figure 52: EPG and MPG of insulation value (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

Total energy use

The total energy almost stays the same; it decreases by less than 1% and is the lowest at Rc=5,5 m^2K/W. With a higher value of 5,5 m^2K/W, the total energy increases. The total used energy when the Rc value is 10,5 m^2K/W is even higher than the total energy with an Rc value of 2,5 m^2K/W. The reduced energy demand by adding insulation is cancelled by the extra energy used for producing the material. In the calculated scenario with 20% glass and 80% closed parts in the facade the total energy is less and lowest for Rc=6,5 m^2K/W and Rc=8,5 m^2K/W. The difference between these values and other Rc values is still limited.

CO_2 emission

The CO_2 emission is in the variant with 80% open parts is constant 52% and in the variant with 20% open parts between 50% and 51%.

2b. Insulation material

Sustainability performance

In this variant the Rc value is kept constant, so only the environmental performance is changing for different materials. On average, the insulation material of the facade has no significant influence on the environmental performance of the building at building level. The sustainability performance is almost the same for all variants, see figure 53. Only isover sonepanel and wood fibre cause an improvement of 1%. The sheep wool is the only outlier; it scores 11% worse than the reference situation. In the current calculations, the allocation of environmental effects is determined based on the financial end products of the sheep. Before, the wool is seen as a waste product of the meat of sheep. Nowadays, the environmental impact caused by sheep is for two-third attributed to sheep wool and for one third to the meat. Therefore, a significant increase in MPG is visible (Nibe, 2019)

The DPG of EPS sheet and cellular glass is 0,01 higher than the reference case. The other insulation materials all result in the same shadow costs. Insulation of wood fibre has the best DPG score. For the scenario with 20% open parts, there is 2,5 times as much insulation in the facade. The influence at building level is still not significant. In this variant also the sheep wool has the highest DPG.

Table 26: Results insulation material 80% open facade

	DPG (€/m²)	*Total energy (MJ)*
NVPU-PU (Reference)	1,32	1.664.575
Rockwool	1,32	1.661.585
Flax wool	1.32	1.663.435
Sheep wool	1.48 (+12%)	1.684.807
EPS panel	1.33 (-0%)	1.665.361
Woodfibre	1.31 (-1%)	1.660.632
Glass fibre	1.32	1.661.714
Aerated concrete	1.32	1.667.120
Metisse	1.32	1.663.256
Cellular insulation bio	1.32	1.660.385
Cellular glass	1.33	1.673.424

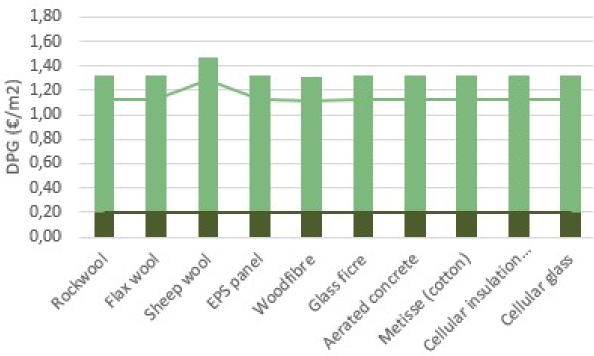


Figure 53: EPG and MPG of insulation material (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

Total energy use

The total energy use has even less variation than the DPG in this analysis. The total energy used when applying sheep wool is 1% more than the reference situation, and the change for the other materials is less than 1%. While some material materials have a better insulation value and thus less material is needed; still, the total energy use is the same.

CO_2 emission

The CO_2 emission is in the variant with 80% open parts is 50% to 52% and in the variant with 20% open parts between 45% and 51%. The variant with sheep wool has the lowest percentage of CO_2 emission but still the highest CO_2 emission.

5.1.3 Variant 3: Change in ratio open/closed parts

Sustainability performance

From literature, it is known that the percentage of open and closed parts in the facade has a considerable impact on both energy and environmental performance. (Nieman & Anink, 2017) This is also visible in the results of this variant. The less per cent open parts, the lower thus better the energy performance of the building. Both heating and cooling are decreasing.

The less per cent open parts, the lower the environmental performance of the building is. In contrast to variants seen before the energy performance and environmental performance do not correlate negatively but positively, see figure 54.

Table 27: Results open closed percentage

	DPG (€/m²)	*Total energy (MJ)*
100% open	1,41 (+6%)	1.736.921
80% open (Reference)	1,32	1.664.575
60% open	1,22 (-8%)	1.577.779
40% open	1,12 (-15%)	1.497.951
20% open	1,02 (-23%)	1.418.373
0% open	0,94 (-29%)	1.351.084

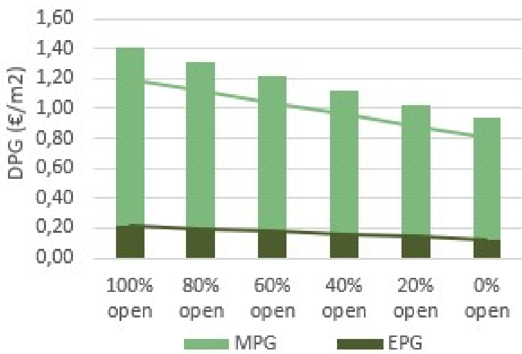


Figure 54: EPG and MPG open closed percentage (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

Total energy use

With less per cent open parts, the building is better insulated and therefore less heating, or cooling is demanded. Also, the embodied energy decreases, the open parts in the facade, mainly glazing, costs more energy to produce than the closed parts of the facade. Therefore the total energy use decreases.

CO_2 emission

The more open parts in the facade, the more heating is needed and also more cooling, resulting in a higher CO_2 emission.

Combination open/closed parts and different glazing
With triple glazing, it is evident that a larger area of glazing uses more material and causes more environmental impacts. The influence of the type of glazing is looked into in this variant by calculating the different percentages also with other types of glazing. The results for HR++ and HR+ are almost the same as for triple glazing. For double glazing the energy performance becomes worse, the variants of double glazing are comparable with triple glazing of HR++ with 20% more open parts in the facade. So 60% open parts with double glazing gives about the same result as 80% open parts with HR++. The variant with HR++ without louvres in the facade has a better total score than with louvres. This effect decreases when the area open parts in the facade increases.

In figure 55, the results of different types of glazing combined with the percentage of open and closed parts are visible. A substantial difference in sustainability performance is noticeable between double glazing and the other types. The triple glazing system has the lowest total energy use and the HR++ without louvres the lowest sustainability performance.

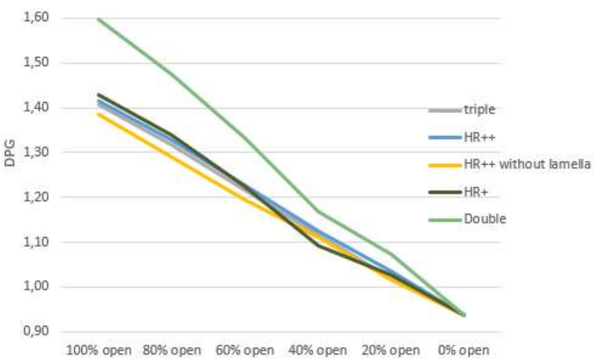


Figure 55: DPG overview of different type of glazing with a change in ratio open/closed parts

5.1.4 Variant 4: PV panels on the facade

Sustainability performance

From this study, it appears that PV panels on the facade have a nett positive effect on the sustainability performance. The PV panels cause an increase in the environmental impact but not as large as the decrease in the energy performance, see figure 56. The most beneficial orientation is south after which east, west and then north. Still, the DPG of PV panels on the north is 1% improved compared to the basic situation, see table 28.

Table 28: Results PV variant

m^2	*orientation*	*DPG (€/m^2)*	*Total energy (MJ)*	*Total energy – induced (MJ)*
0	-	1,32	1.664.575	890.390
114	N	1,31 (-1%)	1.678.618	855.318
114	O	1,29 (-3%)	1.678.618	813.931
114	Z	1,27 (-4%)	1.678.618	783.834
114	W	1,29 (-3%)	1.678.618	814.917
228	Z/O	1,24 (-6%)	1.694.125	750.226
228	Z	1,22 (-7%)	1.694.125	678.742
342	Z/O	1,19 (-10%)	1.708.901	603.016
456	Z/O	1,16 (-12%)	1.723.677	527.290

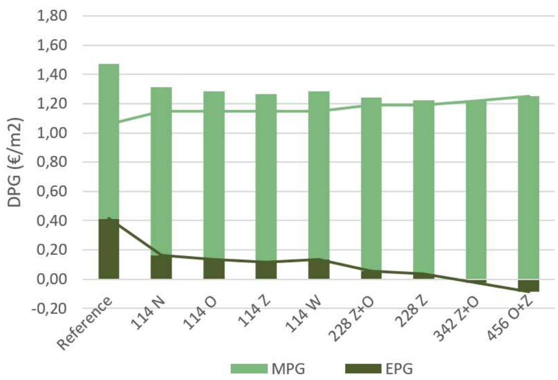


Figure 56: EPG and MPG PV variant (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

Total energy use

The total energy needed in the situation where 114 m^2 PV panels are included on the north facade is 1% more than the underlying situation. More energy is used for the production of the material, and the energy demand of the building does not decrease. However, when subtracting the generated energy from the energy demand of the building, the demand will decrease. When the nZEB requirements are regarded, the generated energy cannot be taken into account to satisfy the first requirement. Therefore the primary goal is to reduce the energy demand of the building.

CO_2 emission

The percentage of CO_2 in the total emissions decreases obviously when more PV panels are added. This is because, when applying 342 m^2 and 456 m^2 of PV panels, the CO_2 emission from the EPG calculation is negative. This means more energy is generated than needed. However, the CO_2 emission, as calculated in the MPG, cannot be compensated by the negative CO_2 emission in the energy performance calculation.

PV panels on the facade seem like an excellent measure to enhance the sustainability performance. A calculation of the Net Present Value is made to show the financial feasibility of PV panels. In table 29, the payback time of different variants is shown and the profit after 30 years for the reference building.

Table 29: Results NPV calculation PV panels

m²	Orientation	Payback time (y)	Profit (€)
114	N	28	€ 2.028,60
114	O	15	€ 27.288,43
114	Z	11	€ 45.657,61
114	W	15	€ 26.686,64
228	Z/O	16	€ 47.692,92
228	Z	11	€ 91.321,93
342	Z/O	12	€ 118.617,08
456	Z/O	13	€ 145.912,22

5.1.5 Variant 5: Sun shading

Sustainability performance

The energy performances of both the roller shades and solid screens are similar. The Rc value in both systems has improved little when applied permanent, and in other situations, the type of sun shading also does not influence the energy performance differently because the g-value is the same. Nevertheless, there is a significant difference in MPG visible. Both sun shading systems are made (partly) out of aluminium and the environmental impact of this material cannot be compensated by an improvement in the energy performance. The solid screens have a relatively lower impact and therefore have a better total score, shown in figure 57 and table 30.

The scenarios without louvres have a better total score because, in the calculation, the louvres have no benefits. The reason for this is because the g-value achieved by the sun shading cannot be lowered with louvres. In reality, this would have a (small) effect. The variant without louvres and with an automatically controlled solid screen has the best score with 1% improvement in DPG. Results are expected to be better when the sun shading is made of a different material than aluminium. Unfortunately, these are not included in the database.

Theoretically, an optimum can be achieved if sun shading is used in winter for insulation at night and is open during the day and is in summer open at night for cooling and is closed during the day. This optimised variant is calculated by a combination of a scenario with permanent sun shading and with no sun shading. The cooling demand of the situation with permanent sun shading will be taken because this reduces much extra solar heat inside the building in summer. The heating demand of no sun shading will be taken because in winter the sun can be used to heat the building.

The optimal variant has a total DPG score of 4% better and total energy use of 8% less than the reference case. In this calculation, the variant with no louvres and with solid screen is used.

Table 30: Results sun shading

	DPG (€/m²)	Total energy (MJ)
Reference facade	1.32	1.664.575
Roller auto	1,61 (+22%)	1.668.742
Roller hand	1,61 (+22%)	1.676.930
Roller permanent	1,63 (+24%)	1.703.381
No lam auto roller	1,53 (+16%)	1.606.543
No lam hand roller	1,55 (+18%)	1.648.210
No lam perm roller	1,55 (+17%)	1.642.518
Solid auto	1,39 (+5%)	1.657.792
Solid hand	1,39 (+6%)	1.665.980
Solid permanent	1,41 (+7%)	1.692.431
No lam auto sol	1,31 (-1%)	1.595.617
No lam hand sol	1,33 (+1%)	1.637.284
No lam perm sol	1,33 (+1%)	1.631.592
Optimal solids	1,26 (-4%)	1.532.390

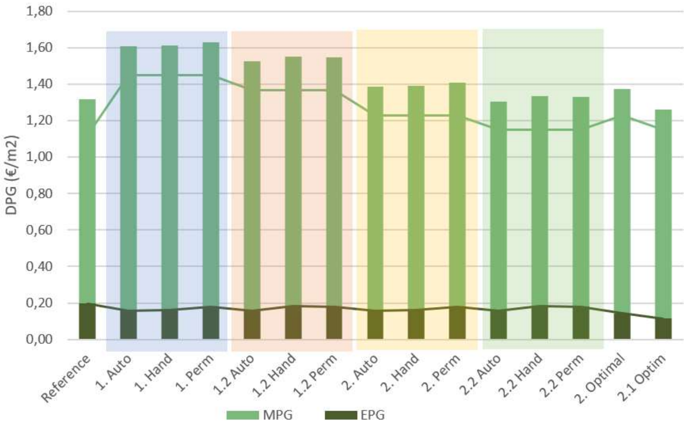


Figure 57: EPG and MPG sun shading (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately) ■ represents roller shades with louvres (1), ■ represents roller shades without louvres (1.2), ■ shows variants with louvres and solid screen (2) and in ■ the results of solid screen without louvres can be seen (2.2).

Total energy use

The variant with no louvres and solid screens has a total energy use of 4% lower than the reference case. The optimal variant has an energy use of 8% less than the reference.

CO_2 emission

The average contribution of CO_2 to the total emission for the roller blinds is about 10% lower than the reference case. The percentage of CO_2 for the solid screens is only 4% lower than without sun shading.

5.1.6 Variant 6: Facade composition

6a. Different materials

Sustainability performance

The energy performance is the same as for HR++ glazing without louvres in all three variants. The Rc value of the facade is kept constant. The MPG has improved in all three designs. This is not only because of a different material use but because no louvres are used. Therefore it would be better to compare the results to the result of the reference building without louvres. The DPG of the wooden design has improved by 8% relatively. The score or the facade with natural stone cladding is enhanced with 5% compared to the reference building without louvres, and the DPG of the concrete facade is 2% lower. In table 31 and figure 58, an overview is shown of the results.

Table 31: Results 6a

	DPG	*Total energy*
Reference facade	1.32	1.664.575
Reference facade without louvres	1,29 (-2%)	1.681.148
Wood	1.19 (-10%)	1.694.650
Natural stone	1.22 (-8%)	1.714.812
Concrete	1.26 (-4%)	1.709.272

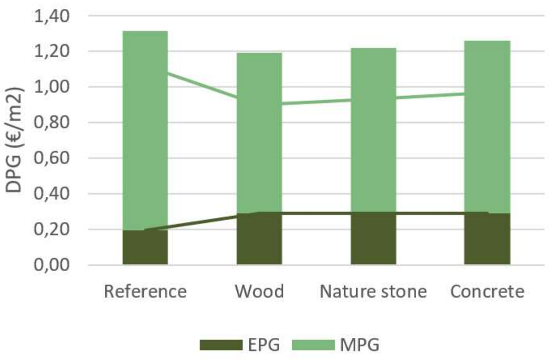


Figure 58: EPG and MPG different facade materials (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

Total energy use

The total energy use is more compared to either the reference situation or reference situation without louvres. Most energy is used in the design with natural stone. However, the difference between the other two considered situations is within 1%.

CO_2 emission

The percentage of CO_2 emission for three facades is slightly higher than the reference situation. This is caused by the difference in the type of glazing and not by the change in materials.

6b. Aluminium louvres and facade panels substituted

Sustainability performance

In this variant, first, the aluminium louvres are substituted by louvres of a different material or omitted. The variant with no louvres has a sustainability performance of 2% better than the reference situation. The energy performance increases with 20%, but in total, the DPG has improved. When considering other parameters such as costs and transport and weight of the facade, the scenario without louvres would also be beneficial. Other effects are evaluated in the discussion. When substituting the aluminium louvres by other materials, there is no significant improvement of DPG, see figure 59. The energy performance stays constant, and the MPG is not decreased significantly by other materials. Although the material wood has fewer emissions per m^3, the thickness of wooden louvres is more than aluminium. Also in the wooden variant, a steel frame is included in the LCA to attach the louvres. Therefore the MPG is even increased by 1% compared to the reference design. This calculation is limited by the database and available data of elements.

When also the closed parts of the facade are substituted by wood the DPG is increased by 3%.

Total energy use

The total energy use when no louvres are used is increased by 1%. The extra energy in the building demand is almost compensated by the decrease of energy needed for the production of materials. The total energy required when other materials are used instead of aluminium is less when using natural stone or cement. The energy with wooden louvres and wooden facade panels is even more. The results in this variant depend on the assumed thicknesses of different materials. Standard thicknesses of example details and data are used. Depending on the requirements, these thicknesses could be limited.

CO_2 emission

Although the total DPG and total energy of the wooden variant are not decreased, the total CO_2 emission has reduced and therefore, the percentage of CO_2 is lower in this scenario. The percentage of CO_2 in the variants with other materials are comparable to the reference situation.

Table 32: Results 6b

	DPG	*Total energy (MJ)*
Reference facade	1,32	1.664.575
No louvres	1,29 (-3%)	1.681.148
Wooden louvres	1,33 (+0%)	1.799.609
Stone louvres	1,29 (-3%)	1.642.488
Cement louvres	1,25 (-6%)	1.611.973
Wooden facade/ louvres	1,36 (+3%)	1.848.798
Synthetic facade/ louvres	1,31 (-1%)	1.657.503

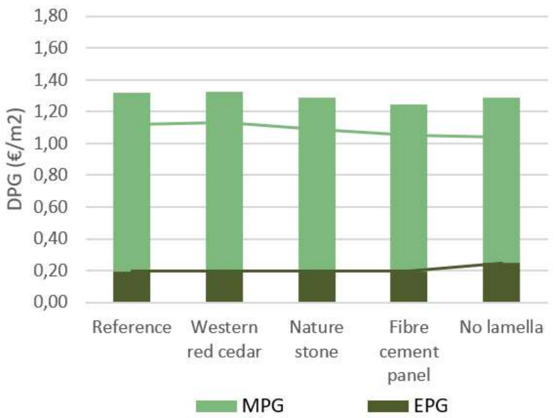


Figure 59: EPG and MPG of different louvres (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

Variant 6c: Facade height

Sustainability performance

Both the EPG and MPG are influenced by the height of the facade, and both will increase when the height is increased. This because the amount of used materials increase while the GFA is kept constant. Subsequently, the loss area in the calculation of transmission losses becomes bigger. When increasing the height of the facade with 10%, the DPG will increase by 2%. The effect is not linear when 20% of the height is added to the facade; the DPG will increase by 6%, see figure 60. In office buildings, it is common to increase the facade height of at least the ground floor of the building, sometimes even with a few meters. This has a significant influence on the sustainability of the building.

Total energy use

The total energy used is also depending on the height of the facade. It increases with the same magnitude as the DPG increases.

CO_2 emission

Also, the CO_2 emission has the same decrease and increase in percentages as the DPG. Therefore the percentage of CO_2 emission is constant.

Table 33: Results 6c

	DPG	*Total energy (MJ)*
Reference facade	1.32	1.664.575
+10% facade	1,35 (+2%)	1.698.881 (+2%)
+20% facade	1,40 (+6%)	1.740.111 (+4%)
-10% facade	1,26 (-4%)	1.615.841 (-3%)
-20% facade	1,21 (-8%)	1.574.148 (-5%)

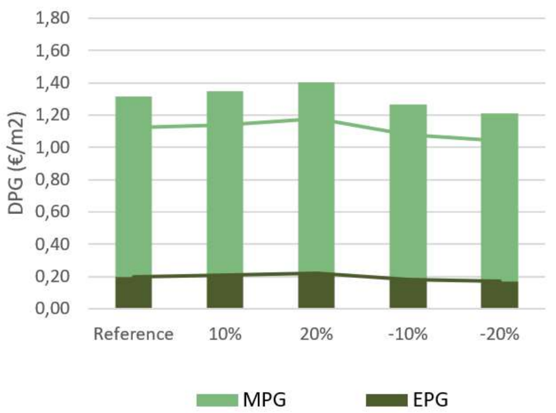


Figure 60: EPG and MPG of different facade height (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

5.1.7 Variant 7: Orientation

Sustainability performance

The orientation of the building influences the energy performance of the building. The design of a building is mostly adjusted to the orientation, especially the windows and sun shading. Remarkably the orientation of the reference building seems to have the worst DPG. The orientation is probably chosen because of logistics and available place.

When the building is rotated clockwise by 90 degrees, the most improvement is achieved, the DPG is 1,29, which is 2% lower. When rotating 180 degrees, almost no difference is noticed, which is logical because the north and south facade are almost similar as are the east and west facade. The orientation with the optimal performance is when the entrance is oriented to the north. The glass areas are then oriented north and south.

Total energy use

The total energy use is also the lowest when rotating 90 degrees, mainly due to a decrease in heating demand. Less solar heat will enter the building. Against expectations also the cooling demand is increased. This can be explained with a calculation of the annual solar radiation for different orientations of the building, see figure 61. In the reference case, the windows are oriented east and west. In the figure, it is visible most heat gain is in summer when least solar radiation is wanted and thus cooling is needed in the summer period and heating in the winter period.

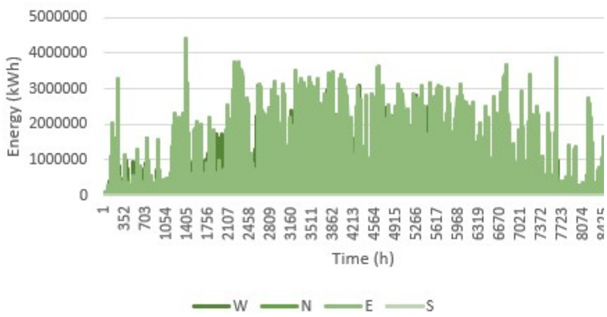


Figure 61: Results solar gain reference case, east and west facade. Based on (NEN 5060:2018 , 2018)

In figure 62, the solar gain on the south facade is shown when the facade is shifted 90 degrees. Most solar heat is gained in the winter period. The solar gain in summer is less compared to the previous variant. Therefore both heating and cooling will decrease when the orientation is shifted.

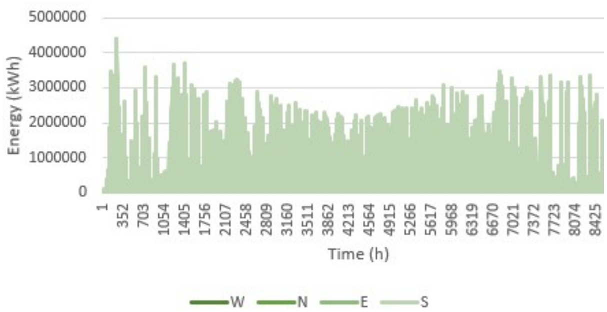


Figure 62: Results solar gain shifted orientation, south facade. Based on (NEN 5060:2018 , 2018)

CO_2 emission

Because of an improvement in the energy performance, the CO_2 emission is also reduced when rotating 90 or 45 degrees.

Table 34: Total DPG and energy when changing the orientation

Shift	*DPG*	*Total energy (MJ)*
Reference facade	1.32	1.664.575
45 degrees	1,31 (-0%)	1.648.927
90 degrees	1,29 (-2%)	1.621.991
180 degrees	1,32 (-1%)	1.644.588

5.1.8 Variant 8: Circular variant

The service life of the building

When increasing the service life of the building, the environmental performance will improve, and the energy performance stays constant. The more years, the less improvement in both total energy and sustainability performance. From 50 years to 75 years, improvement of 16% is made. A service life of 100 years has a sustainability performance of 21% less than 50 years. So from these results, it can be expected that after 75 years the investment to increase the service life is not useful anymore. In this variant, the service life of the whole building was adjusted while the variation of design in this design should be focussed on the facade. To evaluate this influence, in the next section a circular variant is looked at.

The decrease in slope in figure 63 can be clarified by the knowledge that products are being used more optimal regarding the service life. Next to this, also it can be explained by the way the tool is programmed to calculate after the complete service-life of products is reached.

Table 35: Results service life

	DPG	*Total energy (MJ)*
25 years	1,92 (+46%)	1.982.551
50 years (Reference)	1,32	1.664.575
75 years	1,14 (-14%)	1.572.425
100 years	1,09 (-18%)	1.540.763
125 years	1,06 (-20%)	1.521.973
150 years	1,04 (-22)	1.509.274

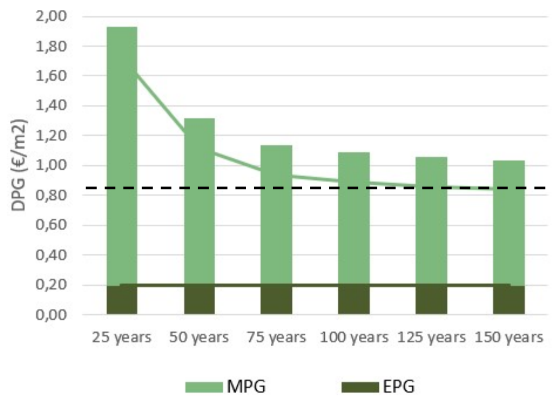


Figure 63: EPG and MPG of the service life of the building (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

When the service life of the product is extended the MPG of that part of the building stays constant.

In the MRPI-MPG tool the following formula is used to determine the number of cycles; Lg/Lp-1 (Lg= service life of the building, Lp is the service life of the product. Every product is applied at least once in the construction, after this time, the number of cycles according to the decimal method (fracture, rounded up). In the first steps until the service life of the product, the product is applied only once but shared by an increasing number of years (the service life is longer, the MPG decreases). After 75 years, the number of replacements increases in the decimal. (Lg is longer and therefore is Lg/Lp larger) However, due to a growing Lg, the loading is shared by a bigger number and is reduced to the same extent. Therefore the MPG remains constant after the service life of the product.

Circular building

In the circular variants, the energy performance does not change, except for scenario 3. The only difference from the reference case is the triple glazing used in scenario 3, a total glass thickness of 12 mm in total instead of 16 mm. Therefore the DPG mostly depends on the environmental performance. The sustainability performance is lowest in scenario 4, as is the total energy demand and CO_2 emission, see figure 64 and table 36.

In scenario 3 and 4, the goal was to minimise the environmental performance. In this section, the results are elaborated per scenario.

Scenario 1

Scenario 1 is the same as the reference case; the DPG is 1,32. The MPG in this scenario is 1,12, which would not satisfy the requirements, as stated by the Dutch government.

Scenario 2

The service life is decreased from 50 years to 20 years resulting in a DPG of 2,35. The performance has more than doubled, caused by an increase of MPG of 92%. When this would be the realistic service life, it would almost be impossible to fulfil the requirement of 1,0 €/m^2.

Scenario 3

The energy performance in scenario 3 is 4% higher than the reference case. The MPG as calculated in scenario 3 is a summation of three calculation with service lives of 20, 50 and 100 years as explained in 4.4.2. The MPG is improved by 3%, and the total DPG is 1,29, which is a decrease of 2%.

The performance of this scenario was expected to be better. Only a small improvement is obtained. The result can be improved when more aspects of the building are designed for a short service life or reuse. This is further elaborated in the discussion.

Scenario 4

When the service life of the facade is increased to 100 years, the MPG is again composed of different parts, together resulting in an MPG of 1,07. The DPG is therefore 1,27, which is an improvement of 4%.

This calculation is hypothetical because, besides the facade, the whole building is designed for a service life of 50 years. Therefore the situation is not realistic. When the service life of the rest of the building would also be 100 years, the DPG would be further decreased to 1,10.

Table 36: Results circular variant

	DPG	*Total energy (MJ)*
Scenario 1 (Reference)	1,32	1.664.575
Scenario 2	2,35 (+78%)	2.205.747
Scenario 3	1,29 (-2%)	1.665.292
Scenario 4	1,27 (-4%)	1.638.956

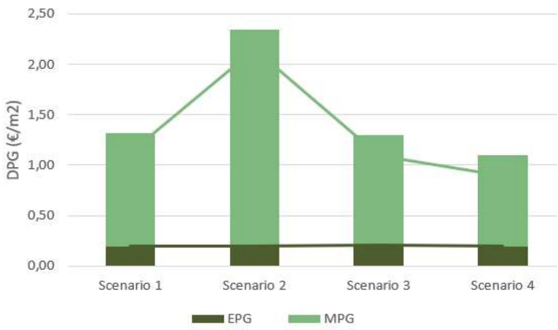


Figure 64: EPG and MPG circular variant (EPG and MPG in column are stacked, and the lines represent the trend in EPG and MPG separately)

5.1.9 Realistic improvement

In this research, a one-factor-at-the-time analysis is performed, which doesn't provide insight into the impact when parameters will be combined. The separate improvement of variants cannot merely be summed because of the dependency between these variants. The goal of this realistic variant is not to select the parameters causing minimal sustainability performance but to take into account practical feasibility. Therefore, based on the results and discussion of feasibility, one variant is calculated with realistic, feasible adjustments to the reference building. The sustainability performance is only focussed on the environmental aspects of sustainability. However, social and financial requirements are boundary conditions for adjusting the design. In this variant, the remaining scenarios when all requirements are satisfied, are adapted. The following measurements are applied:

- Triple glazing with a total thickness of 12 mm instead of 16 mm.
- 60% open parts in the facade instead of 80%.
- 224 m^2 op PV panels added on the south facade.
- Life cycle of the building focused on more reuse and a service life of 20 years instead of 50 years (scenario 3 as described in 4.4.9)

The MPG of this variant is 1,1, and the total EPG of this variant is 0,02. The total DPG of this variant is 1,12, which is an improvement of 15,5%. The total energy has decreased by 10% when induced energy is taken into account and with 2% when induced energy is not taken into account. The variant will also fulfil the nZEB requirements. The total CO_2 emission is 13% lower than in the reference situation.

6. DISCUSSION & CONCLUSION

In 6.1, the discussion, the reliability of the results is evaluated. Besides, some remarkable results will be discussed and explained. In paragraph 6.2, the research questions, as stated before, will be answered to conclude this research. Then, in paragraph 6.3, recommendations will be given for future research on this subject.

6.1 DISCUSSION

The results of the case study as described in chapter 5 suggest one value per variant to be the most sustainable because of having the lowest sustainability performance. However, in this section, several aspects of the research methodology, calculations and results are discussed to be able to formulate conclusions and to show the limitations in this research. The usability of the results is examined with a sensitivity analysis of the results.

6.1.1 Reference building

The calculations of the MPG and EPG, done in chapter 4 and 5, are used as a starting point for the calculation used in this research. As described in chapter 4, not all materials are taken into account, and not all parameters of the environmental performance calculation correspond to the numbers used in energy performance calculation. However, for this research, it is particularly important to have a constant reference case to refer to and compare with. Therefore the relative results would not be influenced by a different reference case.

The reference building was built in 2017 and was designed as a sustainable building, in particular, energy-efficient. Should an older building have been used for this research, then the impact and need for enhancing the sustainability performance would be more clear. It is also quite challenging to improve the DPG with the imagined circular scenario's because the facade has a curtain wall system. Since glass can only be recycled, a large part of the facade cannot be reused; however, the aluminium profiles can be reused. Curtain wall facades can even be better reused than other facades because in windows joints are glued by a mixed adhesive. (Fuchs, 2019)

6.1.2 Decisive measured parameter

Along with the DPG, we looked at the total energy used and the total CO_2 emission of all variants. Which parameters will be normative for the most sustainable variant? In this research, the total energy, as well as the total CO_2 emission, are included as emissions in the DPG. Therefore the DPG is overall the most critical parameter. However, the total energy use and CO_2 emissions are relevant to look into as well for several reasons. The total energy demand is essential for the total costs of the project and financial feasibility. The total CO_2 emission is essential because the Dutch government is steering towards a CO_2 neutral building industry. The percentage of CO_2 in the DPG is quite constant, visible in figure 65. In all variants, the share of CO2 in the DPG lies in between 40% and 60%, excluding a few outliers such as single glass with 67%. Therefore when steering on lowering the total CO_2 emissions, the sustainability performance will undoubtedly reduce with a factor of 0,4-0,6 times the percentage of CO_2 reduction. So for example, when the climate objective would be reached of reducing the CO_2 emissions with 50%, the DPG would have a reduction of 20-30%. However, the correlation between CO_2 and DPG is not always positive. For example, the DPG of vacuum glazing made of 2x3mm glass panels is improved by 5% compared to the triple glazing. Nevertheless, the total CO_2 emission has increased by 3%. Also, the government is only steering on the total Dutch CO_2 emission. In LCA calculations, also international CO_2 emissions are taken into account. This is another reason to consider the emissions caused by energy and material use integral.

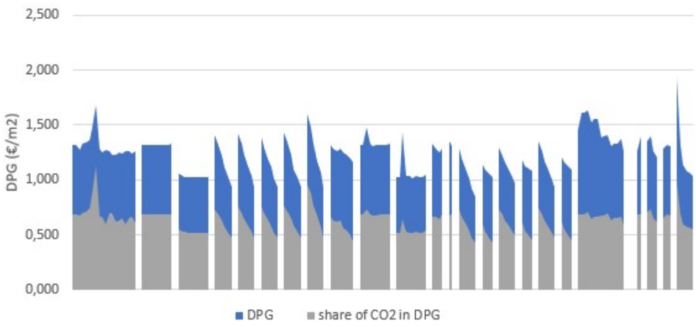


Figure 65: DPG and share of CO_2 in DPG of all variants (different variants are plotted on the horizontal axis, the type of variant is not meaningful in this case)

In this research, the DPG is derived from the EPG and MPG calculations. However, the DPG could also be extracted from an LCA analysis of the building. In the life cycle stage B1, the use phase, which represents the EPG, is taken into account, see figure 19. This shows that the DPG as a summation of the EPG and MPG is no completely new requirement, the EPG and MPG are both split off the LCA.

6.1.3 Variants

In this section, the outcome of the case study as summarised in figure 65 will be discussed. In this figure, the scenario in which the sustainability performance is lowest is highlighted per variant. In this section, the feasibility of those optimal design parameters is discussed.

Glass variant

As described in paragraph 5.1, triple glazing with a thickness of 12 mm has the lowest sustainability performance of the conventional glazing types. Also, the total used energy is less than the reference case. When taken into account the results described in 5.2, the triple vacuum glazing has a lower DPG. When not including the louvres in the design and adding sun shading, the DPG will decrease even more.

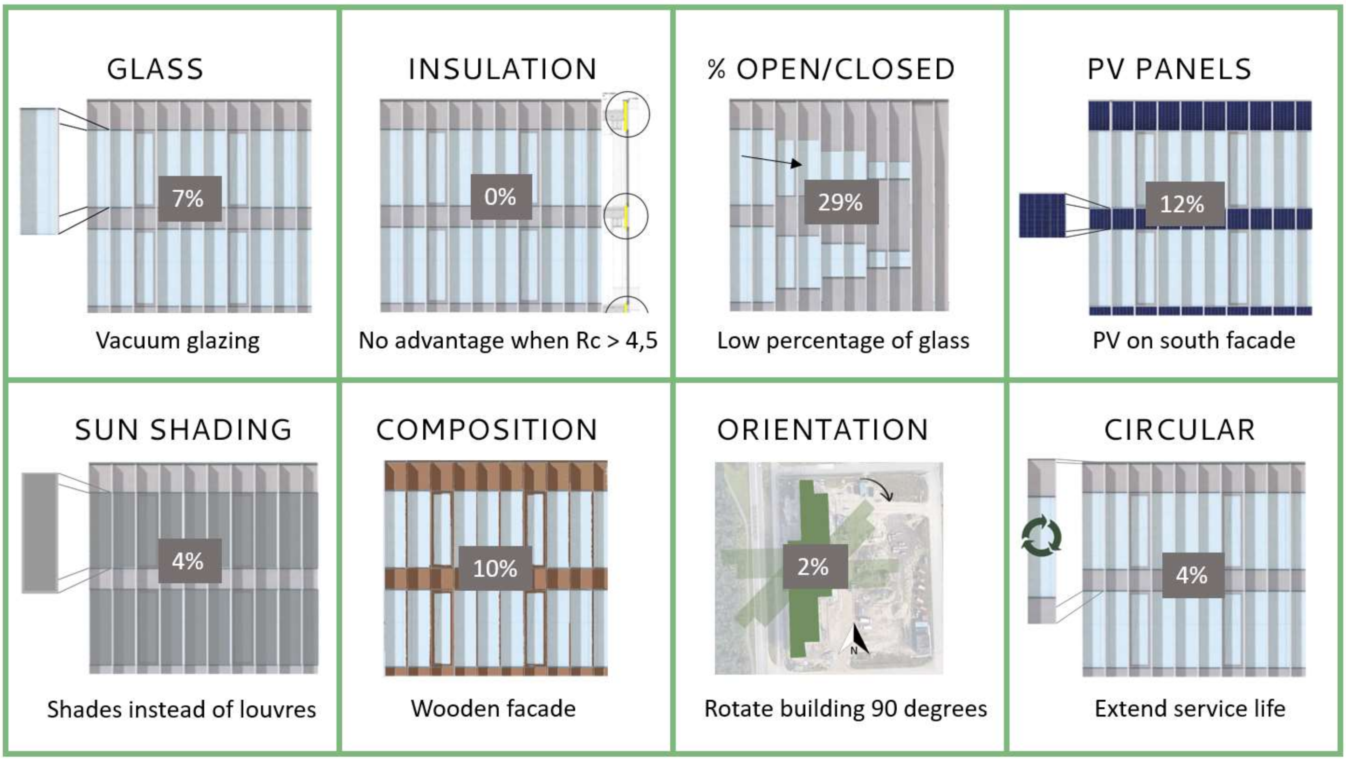


Figure 66: Optimal scenario's in the calculated variants. The percentage corresponds to the improvement in sustainability performance of the reference building per variant.

In the calculation of the type of glazing variant, some assumptions are made to simplify the calculation or because of missing data, such as the information about the production of vacuum and gorilla glazing. Some simplifications can influence the results. For example, thinner glass results in more incoming daylight, which has consequences for the lighting in the building. These effects are neglected in this research, but it might be interesting for a more detailed study.

The type of glass also affects other elements in the facade and the structural system of the building. The weight of the glass is changing a lot throughout the different variants, which is determining the size of the frame and structure of the building.

In the vacuum glazing, steel pillars are included causing small cold bridges in the glass which are not included in the calculation. The used values as input for the EPG calculation of different thicknesses vacuum glazing are based on fact sheets of different producers. The production process could be different for other producers, and along with the production, the impact can be slightly different. Also, the service life of vacuum glazing is longer than conventional glazing types. However, the insulation value of vacuum glass is likely to deteriorate earlier because it is hard to keep the vacuum in this type of glazing. The edge sealing of vacuum glazing mostly determines the service life. (Koebel, Manz, Mayerhofer, & Keller, 2009) The edge sealing method is also a problem for conventional glazing. Since the service life of conventional glazing is 25 years, a service life of 50 years for vacuum glazing seems overestimated. Therefore, the service life is assumed to be equal to conventional glazing.

The energy performance of this variant could be determined very accurately as well as the environmental performance. However, for vacuum glazing and gorilla glazing assumptions were made of the production process. As described in 5.1, the extra energy needed and therefore, extra caused emissions would not significantly change the outcome.

Since triple glazing is relatively new, there is only one variant of triple glazing in the database yet, in which coatings are not included. Therefore, the variants with triple glazing would have a slightly higher environmental performance than estimated. This difference will be about 0,03 €/m^2.

Although triple glazing with a thickness of 16 mm has a better energy performance, the costs are substantially more than other types of glazing which does not make it financially attractive. The sustainability performance of triple glazing with a thickness of 12 mm is better than triple glazing with a thickness of 16 mm, and also the energy reduction cannot cover the extra costs made in the investment. Also, when considering the costs of HR, HR+ and HR++, the extra costs of triple glazing with a thickness of 16 mm would not be paid back within the service life.

Insulation variant

At building level, the insulation value, as well as the insulation material, has no significant influence on the sustainability performance of the building. However, other parameters are influenced by a change in Rc value and/or a different insulation material used. With a higher Rc value or a material with a higher heat conduction, the insulation will become thicker and can be heavier.

Although the difference in DPG and energy is not significant at building level, the difference in energy use among the variants Rc=1,5 m^2K/W and Rc=5,5 m^2K/W is 5585 MJ per year. The insulation values 1,5, 2,5 and 10,5 m^2K/W have a (small) detrimental effect on sustainability, so it is better not to apply these insulation values. When looking in more detail to the total used energy, the difference in Rc=3,5 m^2K/W and Rc=6,5 m^2K/W can be neglected.

Apart from the sheep wool, the insulation material has no significant influence on the sustainability performance. Although sheep wool is renewable, the production process can be more energy demanding than the other materials. The difference in impact can also be caused by the PE foil, serving as a vapour barrier, which was added in the MPG calculation to prevent moisture in the insulation. (W/E adviseurs, 2019) Regarding the other materials, compact and light materials are beneficial because less space is needed. Therefore other materials of the building can be smaller as well.

Percentage open/closed

The less open area in the facade, the more sustainable the facade will be. However, the trend in office buildings is evolving in the opposite direction. The percentage of open parts in the facade increases and this harms the sustainability of the building. Because of this trend, the recommendation to reduce the percentage of glass in the facade will unlikely be adopted in design.

A high percentage of glass is not sustainable, but with a lot of measures, a building can be made energy-efficient. However, the position of design is then already in a sub-optimal field because only more material needs to be added to improve the performance.

A more commonly used solution for the energy efficiency in facades with large percentages of glass is the use of a double-skin facade. With a double-skin facade, again 100% or more of the facade area of glass is added to the environmental impact. For office buildings, it is expected that it is not feasible to fulfil the MPG standard of 1,0 €/m^2 when applying a double skin facade. In the reference building, the curtain wall facade is responsible for 40% of the total impact, when this would be doubled, the MPG would be around 1,7. Probably less aluminium is needed in the second skin and also a different type of glass can be chosen, but still a lot of material is added, and it will be hard to lower the MPG drastically.

PV panels on the facade

The results show that next to PV panels on the south, east and west facade, also PV panels on the north facade have a positive effect on the sustainability performance. However, it is way less effective than the other orientations. Also, because of the costs for PV panels and scarcity of materials used to produce the PV panels, the small decrease in DPG is not worth the adverse effects that are not taken into account in the DPG.

Adding PV panels on the facade or the roof is a good measure to make a building more sustainable. However, the new nZEB (BENG in Dutch) requirements cannot be satisfied when only PV panels are added. Also, other measures are needed to limit the energy demand. The introduction of the nZEB requirements is an excellent way to limit the primary energy demand of the building, but when too many materials are added to accomplish the requirements, it would not be beneficial to achieve a more sustainable building.

As explained in section 2.4.1, only the PV panels that are needed to fulfil the energy performance requirements are obliged to take into account in the environmental performance calculation. In the existing calculation of the reference building, all PV panels are taken into account. Also, in this research, no used PV panels are left out of the calculation. This way, a fair comparison for emissions to the environment is made. However, the MPG of the building would actually be lower in most scenarios than calculated in this research.

In this variant, the assumption is made that the available PV panels in the database are suitable for the facade. In the environmental impact also the frame is included, so no difference in systems suitable for the facade will be expected. Also, other types of PV cells are available such as thin-film cells; these have higher transparency and are cheaper but are less efficient. The MPG of thin-film cells is slightly lower than crystalline silicon cells, which is found by changing the type in the calculation. The crystalline silicon cells are nowadays the standard applied PV cells and are also applied on the roof on the reference building. Therefore this type of PV was also chosen for the facade.

Sun shading

Most of the options of different sun shading results in an increase in DPG. Mainly this is because of the building already has louvres, and apparently, the MPG of these louvres is lower than the MPG of the sun shading used. Sun shading has less influence on the sustainability performance than expected; it is applied in almost every office building for comfort and indoor climate conditions. The scenario with optimal values for heating and cooling can be achieved when a smart system is used to open and close the shading. Nowadays the screens are only closed when sunlight is too much or too much solar radiation is noticed in the building. The sun shading is never closed in the winter during the night to limit cooling of the building.

Although the sun shading in the calculation is not advantageous and the existing louvres in the building would not be necessary, the louvres contribute to a comfortable indoor climate. Therefore some type of sun shading is necessary to fulfil the requirements.

Facade composition

Different facade system and other materials used in the facade

The most important assumption made in this variant is the thickness of the facade cladding materials; wood, concrete and natural stone. These thicknesses are derived from standard details used in existing buildings. When performing a sensitivity analysis on the thickness, it appears to have a little influence on the total MPG. When, for example, 50% of the thickness of the wooden cladding is added, no change in MPG is visible. Also, for the concrete facade, a 50% thicker outer facing will not result in an increase in MPG. Only for the natural stone cladding, a 1% increase in the MPG is visible when increasing the thickness with 50%, which is a negligible difference. Therefore, the results will be a proper estimation of the change in impact when changing a different facade system.

Aluminium substituted

The variant in which no aluminium louvres are added in the design has an improved DPG score and also seems to be more favourable regarding other aspects of the building such as a lighter structure and a reduce in labour and material costs. Also, the transport can be reduced along with the emissions. The reason integrate louvres in the design is because of privacy, indoor climate and comfort. For sustainability reasons, no louvres would be included in the design. However, comfort is critical in the design of the building and is depending on the function of the building decisive.

Height

The DPG is increasing along with the increase in the height of the facade. This result was expected and shows that an increase in storey height has a significant influence on the sustainability performance of buildings. In residential buildings mostly the minimal height of storeys is held on to but in office buildings and public buildings, the storey height is often increased, especially on the first floor. In this variant, especially the ratio between the height of the facade and gross floor area is essential. When the building is higher, and thus the facade, it will not necessarily mean the DPG is increasing because the gross floor area can also change. However, in this variant, the gross floor area was kept constant.

Orientation

The orientation of the office affects the DPG. The performance of the actual position of the office building is worse than the rotation of 45 or 90 degrees.

The rotation of the building is adjusted to the environment, access to roads and surroundings, so this will be different per building. However, the results show that there is room for improvement and that orientation can influence the energy performance of the building. In case of the reference office, no other buildings are a hindrance to rotate the building by 90 degrees. Only the main entrance would not be on the main road anymore. Other factors, such as the direction of the road, are normative and not the performance of the building itself.

However, in the calculation of the orientation the g-value of the windows is not adjusted. The g-value of the reference building is determined by the effect of the louvres. When the building is shifted, the louvres will have a different effect because of the slope towards the sun. Therefore, a more detailed study of the influence of the rotation on the g-value should be performed before knowing the preferable orientation of the building.

Circular variant

Scenario 2 shows that the MPG massively increases when the office building would only satisfy all requirements for 20 years. It is complicated to predict the demand of building types in the future and development in the building industries. Only lessons learned from the past and present and ongoing developments can be considered. However, the building industry is subjected to an enormous energy transition, and lots of offices need to be renovated or rebuilt. Therefore, it is crucial to think of strategies of reuse, rebuilding and recycling such as in scenario 3.

Scenario 3 has less improvement than expected. However, when designing the building particularly for 20 years, the total MPG could be reduced significantly because the design of the whole building can be taken into account. Different materials can be used, and the entire design will be focused on a service life of 20 years.

Another reason for the moderate score of scenario 3 is the glass, which is responsible for a large part of the MPG, is replaced after 20 years while the service life is 25 years. When performing a sensitivity analysis on the service life, the scenario in which the building is designed for 25 years has an improvement of 3% regarding scenario 3, see table 37. Then the DPG is improved by 5%, and the total energy use is 1% less. However, when designing the building for 25 years, other safety factors and loads have to be taken into account, which can influence the amount of material used in the beginning. Besides, 3% is in the same order of magnitude, which indicates scenario 3 is well estimated.

In scenario 3, the most critical assumptions were, next to the service life, the percentage of reuse and the percentage of less material needed in the design of the facade. When instead of 90% of aluminium, 60% of aluminium would be reused the DPG increases with 3% compared to the reference case. The difference is not that large, but it would be decisive in whether scenario 3 or scenario 1 would perform better. So when less percentage of reuse can be realized, scenario 3 would not be beneficial. The influence of the percentage of material reduced in the design is less than the percentage of reuse. In this sensitivity analysis, when only half of the reduction in the material would be realised, 5%, the DPG will still be lowered by 1,5%.

Table 37: Important results sensitivity analysis

Changing parameter	*DPG (€/m²)*	*Total energy use (MJ)*
Service life : 20 years (assumed value)	1,29 (-2%)	1.665.292
Service life : 25 years	1,25 (-5%)	1.641.553
% reuse : 90% (assumed value)	1,29 (-2%)	1.665.292
% reuse : 60%	1,35 (+3%)	1.698.606
% less material : 10% (assumed value)	1,27 (-4%)	1.638.956
% less material : 5%	1,30 (-1%)	1.078.139

The building designed in project XX can be used as an example for the circular building approach. The most used material in the facade is glass. Furthermore, the structural frame is made of laminated wooden beams and steel profiles. The pipes are visible and not concealed, and the air ducts are made of cardboard. (Klomp & Post, 1999) Although the reference building can be improved when the design was focused on 20 years, some elements are already similar to project XX.

Even though scenario 4 results in the lowest DPG, the scenario is the least realistic. There is only a small chance that the office building will remain intact for 100 years. In scenario 4, the replacements needed are taken into account by the MRPI-MPG tool. However, it is unclear what amount of extra material is taken into account. When for example an extra layer of glass has to be added in 50 years, the amount of material is underestimated in the model.

The chosen reference building has, of course, tremendous influence in the improvement of measures. Since the office is a relatively new and sustainable building, it was harder to improve the performance when building circular.

It is still very challenging to design according to circular principles because the whole building industry, including the Eurocode, is not adjusted to circularity. The Eurocode provides requirements for materials and building products which are tuned to the linear building process.

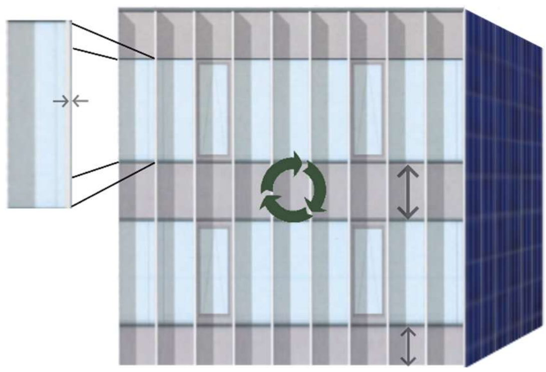
Also, the method of calculating the EPG and MPG is not adjusted to the circular building approach yet. It is possible to reduce the impact of materials with the inclusion of module D, as can be seen in figure 19. However, it is not clear what rules need to be applied and what assumptions need to be made.

Realistic variant, optimised design

In chapter 5, the results of a combined variant with realistic adjustments are described. The adjustments are derived from the beforementioned discussion of variants. In the realistic variant triple glazing with a thickness of 12 mm is used because the technical and financial feasibility of glazing types with a better sustainability score, such as vacuum glazing, are insecure. The current insulation value of 4,5 m²K/W is not changed in the optimised design because the insulation value wouldn't change the sustainability performance significantly. The share of open parts in the facade is diminished to 60% to decrease the sustainability performance and keep enough transparency, daylight and the character of the building. On the south facade, 224 m² of PV panels is added to efficiently gain energy and improve the energy performance. The louvres of the building are maintained to preserve comfort in the building. Furthermore, the building will be designed for a service life of 20 years with focus on a high percentage of reuse of materials, as described in scenario 3 in 4.4.9.

These adjustments will cause an improvement of 15,5% of the sustainability performance. This is a significant change, and the design is feasible in practice and will most likely also be cheaper. It will be less expensive because less glass is used in both thickness and area and materials can be reused. Also, the investment of PV panels is already paid back in 11 years. This improvement shows that the reference building is designed on energy efficiency and impact of materials is not taken into account.

The optimal improvement of a combination of variants cannot easily be obtained by a summation of results. An estimation can be made, but the variants influence each other, and therefore the real value will diverge. For example, in this variant the percentage open parts in the facade is reduced which results in less improvement when the type of glass is changed.



6.1.4 Database

For all MPG calculations, the same database is used. The use of this database also has its drawbacks in this research. First, not all data are public or traceable. The results are highly dependent on the used database, and the data cannot be checked. Some of the elements can be found in the public database of nibe.com, but in other cases, no background information is known of the elements. Therefore, it is recommendable to use an exact material profile when implementing measures in the design.

The second drawback is that the available data in the database is still limited, and some data is not tested yet. Producers have to pay to include their product in the database. The costs for including a product are not affordable for all producers.

The third disadvantage of the database is that only the standard 11 impact categories are taken into account in the calculation, visible in figure 19. Other aspects that are significant in terms of sustainability are not taken into account because of a lack of methods to quantify these categories. Examples of these categories are land-use, water-use and produced waste.

6.1.5 Generalization

Before, the results are analysed, especially for the reference building. This research, however, is also applicable to other office buildings. Some conclusions are also valid for public and/ or residential buildings.

Variation in the type of glazing applies to all buildings because all facades of office buildings have a significant percentage of windows. The influence of the type of glazing is combined with a change in percentage of open and closed parts in the facade, and therefore the influence can be predicted for other office buildings with less area open facade. The difference in DPG of different glazing types decreases when the total area of the window decreases. However, because of a decrease in the DPG, the percentages of improvement stay more or less constant.

The results of the insulation variant can be used to substantiate that the focus on insulation values might be reduced. For attached or even larger office buildings, the insulation value would even affect the performance less. In residential buildings, the percentage of closed parts in the facade is on average higher than in office buildings. However, the variation in insulation value is also calculated with 20% glass in the facade and can therefore also be used for residential buildings. The ventilation, heating and cooling systems can change per building and will also affect the results. However, to reduce the demand, passive measures must be looked into first.

The change in the percentage of open and closed parts will also be significant regarding other office buildings. The difference will depend on the facade system and materials chosen. Despite that, in this research, it is shown that also when the glazing is HR++, HR+ or HR++ without louvres the open part of the facade will still cause more emissions in both EPG and MPG than the closed part of the facade. Not only the glazing system is changed with the percentage of open and closed parts but also the material in the facade is varied, and the same trend can be distinguished.

The PV panels are not integrated into the design, and the result is therefore not depending on other properties of the building, assuming the facade is vertical. It is also assumed no other buildings or for example trees are blocking the sunlight. Currently, PV panels can be seen as an add-on; however, in future design, it can possibly be integrated into the roof covering or facade cladding.

The effectiveness of sun shading has a lot to do with the design of the building, window area, orientation and location. Therefore, the results of the sun shading variant are especially useful for the reference building. In the reference building, there is already a type of sun shading. The addition of sun shades seems not to be beneficial but can be favourable in other buildings.

The impact of change in materials depends on the existing structure and if the energy performance is influenced by the change or not. In general, the DPG of the design when choosing wood as cladding material will be lower compared to aluminium panels. The impact of the height of the storeys will be equal in other office buildings because the same percentage of extra materials is needed.

The best orientation of the building is very dependent on the design and location. However, for office buildings with a design with two facades with windows, the best choice is to orientate the windows north and south instead of east and west.

The influence of the circular variant will very much depend on used materials, service life, used connections and production of the materials. The potential of the concept of circular buildings is also seen in other buildings but can hardly be proved in this research.

6.1.6 Integral approach sustainability

The MPG and EPG are strongly connected as they can be both extracted from the LCA and can be summed; however, requirements are set up separately.

Since the MPG is relatively new and there is quite some awareness for the energy transition, the focus is on the EPG. As can be seen in the results, the lowering of the EPG can have a negative effect on the total score, the DPG. For example, when adding sun shading to the building both in the variants with and without louvres, the EPG has improved, but the DPG increases significantly.

New versus renovated buildings

This research is focussed on new buildings. However, renovation is currently very important and corresponds to the line of circular building. Therefore the impact of different variants in the facade is also interesting to know in case of renovation. It is expected that in renovation projects, the sustainability performance can significantly improve when comparing to a scenario of demolition.

Sustainability can also be mainly improved when looking at the current state of some buildings. For example, in some buildings, single glass is still present.

Policy recommendations government

Regarding the current requirements (EPG=0,8, MPG=1,0) the reference building would only fulfil both requirements in the following situations:

- Replacing triple glazing by 2x3 mm vacuum glazing
- Instead of 80% open facade, 20% open facade
- Instead of 80% open facade, 40% open facade with HR++ glazing and no louvres
- Instead of a curtain wall system of aluminium, a wooden facade
- Having a service life of 100 years for the whole building, instead of 50 years

Although the requirements would be satisfied with these measures, these scenarios are not especially the variants with the lowest DPG, which indicates the level of sustainability of the building. Therefore separate requirements will not lead to more sustainable buildings and stimulate the design of sustainable buildings. Therefore a combined requirement should be considered in which the DPG should be below a certain value, see the equation below. Regarding the current requirements, the total would be DPG<1,8 €/m^2. This is based on the current value of MPG, which is easily attainable. From the results, it appears the DPG for this building is far below this value. Therefore a first requirement for the DPG can be 1,4 €/m^2. Most of the variants will fulfil this requirement because the building is very energy efficient already. Only variants with 100% open facade, sun shading, double and single glazing and a service life of 25 years won't meet the requirement.

It would also be useful to consider requirements for existing buildings and renovated buildings. We can achieve more when taking into account larger parts of the building industry.

6.2 CONCLUSION

In this section, first the sub-questions of this research will be addressed and answered. Subsequently, an answer to the main research question will be given. The conclusion is from a scientific perspective and relevant in research. Should the reader be interested in practical recommendations for design or optimisation purposes, then he should refer to chapter 5, the results and 6.1, the discussion.

6.2.1 Sub questions

1. What are the relations between sustainability, energy performance-, environmental performance- and the circularity of buildings?

Sustainability in the context of the building industry focussing on the planet aspect is the outright goal which needs to be acquired to limit the emissions from the building industry to the environment. Different approaches and methods are developed to reach this goal and are already available. Circularity is an approach in designing to strive towards more sustainable buildings. The energy performance of buildings (EPG) and environmental performance of buildings (MPG) are requirements set by the Dutch government to limit emissions and extensive use of materials with a lot of environmental impacts and thus to enhance the sustainability in the building industry. Therefore, there is a goal- means relationship between sustainability and energy performance, environmental performance and circularity.

2. How are the environmental performance and energy performance currently combined in methods and tools to indicate sustainability, and how should these parameters be combined to enhance sustainability?

Currently, several methods exist in which the energy performance and environmental performance are combined. The DPG is an objective method that combines these performances by converting the total CO_2 emission of the energy performance to shadow costs and by adding this to the shadow costs as calculated in the environmental performance. The DPG thus indicates the total emissions of the total life cycle of a product, process or building and the total costs required to bring the environmental impacts of a product, process or building to an acceptable level. (Wright, 2011) The DPG is expressed in shadow costs per square meter, €/m^2.

Other tools such as BREEAM and GPR-Gebouw are designed for the market and are not suitable for this research because next to the EPG and MPG, other parameters are taken into account.

The energy performance and environmental performance do not have to be factorized when they are combined, in contrast to what other studies state (see chapter 3). Both performances can be converted to the same unit, and the calculated emissions correspond. Therefore, by summing the EPG and MPG, one unequivocal performance can be indicated from which it is immediately clear if the sustainability performance is enhancing or diminishing.

3. How should the design of office building facades be approached in the Netherlands when implementing optimized environmental performance and energy performance requirements?

The design of office buildings should be approached by implementing measures to lower the total sustainability performance. Per design parameter, there is an optimal value to minimise the sum of energy performance and environmental performance. By means of a one-factor-at-the-time analysis and consideration of social and economic feasibility, the optimal strategies for eight different parameters can be found, summed below.

Glass
When considering only the sustainability performance of the glass, vacuum glass is the best option to use; although quite expensive. Triple glazing with a thickness of 12 mm would be a least expensive alternative and also has an improved sustainability performance. The triple glazing with a thickness of 16 mm is not paid back when comparing it to either triple glazing with a thickness of 12 mm, HR++ or HR+ glazing.

Insulation
The current Rc value of 4,5 m^2K/W in the reference building is sufficient and more insulation has no additional effect on the sustainability performance. The share of insulation in the environmental impact is rather small. Therefore a search for more sustainable or renewable materials will not result in a better sustainability performance. The only material that is not advised to use is sheep wool, due to the high environmental impact.

Percentage open/closed
The less open area in the facade, the better the sustainability performance of the building. However, the trend in office buildings is to design higher percentages of glass in the facade. To limit these effects, the focus should be on the development of sustainable types of glazing.

PV panels
Integrating PV panels on the south, west or east facade is beneficial for the sustainability performance and financially feasible. Nonetheless, to satisfy the first requirement of Nearly Zero Energy Buildings, other measures need to be taken as the use of PV panels does not limit the primary energy demand for heating and cooling.

Sun shading
Only when the sun shading is used optimal, which means it will be closed during cold nights and warm days and will

be open during hot nights and cold days, the sustainability performance is improved.

Facade composition
A change in the facade system and materials can significantly reduce the sustainability performance. However, this is mainly caused because no louvres are added in the other examined facade designs. Therefore the addition of louvres is not sustainable; neither is increasing the height of the floors. The facade with wooden cladding has the best sustainability performance.

Orientation
The orientation of the building can have a noticeable influence on the sustainability performance of the building. For this particular case of the reference office, the building should be rotated by 90 degrees to enhance sustainability.

Circular building
A circular building approach can be used to improve the sustainability performance of buildings. An extension of the service life of the whole building is the most effective scenario. However, the risk of not fulfilling the functional or aesthetical requirements within the extended service life is significant. Thus, it is preferable to focus on a scenario where materials are reused or recycled; this could potentially reduce the sustainability potential even more than calculated.

6.2.2 Main research question

'How can the Dutch building industry achieve sustainable buildings by designing according to both the energy performance and environmental performance of buildings applied on facades?'

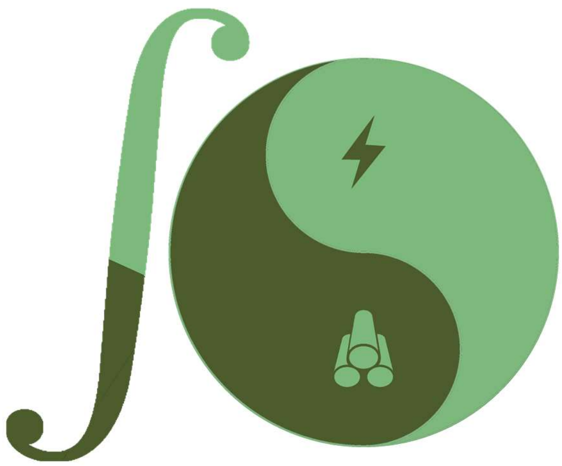
The Dutch building industry can achieve more sustainable buildings when the design is focused on decreasing the sustainability performance of buildings, which is a summation of the energy performance of buildings and the environmental performance of buildings.

An integral approach is essential when enhancing the sustainability performance of buildings because the energy performance of buildings and the environmental performance of buildings have a negative correlation.

For the reference office used in this research, an improvement in sustainability performance of 15,5% can be achieved when measures are implemented focused on lowering the combination of energy- and environmental performance of buildings. Although the reference office already is an energy-efficient building; with an integral approach the building can be significantly improved regarding sustainability.

The goal of the Dutch government to steer on CO_2 emissions can influence the improvement of the sustainability performance, but the relationship between the sustainability performance and CO_2 emission is not entirely linear. The reduction of CO_2 emissions should, just as circular building, be an approach to reach more sustainable buildings but not a goal in itself since CO_2 is not the only parameter affecting the DPG. A lower CO_2 could even result in a higher DPG.

It is relevant to develop systems to generate energy such as PV panels. However, the impact of the used material must not be overlooked. It is essential to use the material in a more circular manner while taking into account the use of energy for its production. Energy and material use need to be balanced together to accomplish a sustainable optimum.



6.3 RECOMMENDATIONS FOR FUTURE RESEARCH

This research can be used to optimise the sustainability performance of buildings by the design of facades. To be able to use this knowledge in a broader context and enhance the sustainability of the building industry, several recommendations are made in this section.

6.2.1 Research method

Combination of factors (multiple factor analysis)

In this research, a one-factor-at-the-time analysis is performed. One facade design parameter is assigned different values to examine its influence on the sustainability performance. A study of the influence of varying multiple design parameters can postulate unexpected influences of combined parameters.

Design of the whole building

To limit the scope of research, the variations in design were all focussed on the facade in this research. A large part of the building design was kept constant. However, the rest of the building can also have a significant influence in reducing the sustainability performance of the building. Therefore a case study in which all design parameters of the building are taken into account is recommended.

More buildings as reference

Another limitation of this research is that only one building is used as a reference case. When the parameters are varied, and results are interpreted of different buildings, more general conclusions can be drawn.

Renovation scenario

In this research, only the performances of the design of new buildings are taken into account. The potential of formulating requirements for the sustainability performance of buildings is a logical step to examine because of a large demand for renovation of buildings.

LCA method

More knowledge on how to use the circular building approach in the calculation of LCA methods must be gathered and spread. In this research, it was difficult to calculate the circular scenarios. The tools and databases are not developed yet to take into account reuse or recycling. When the reduction in impact and/or costs becomes widely known, it will be more appealing to use this as a design approach.

Sustainability in a broader context

The social and economic aspects of sustainability are left out of scope in this research. When expanding this research, social and economic aspects need to be considered so see if the 'most sustainable' measures are also socially acceptable and financially feasible.

6.2.2 Specific research variants

Vacuum glazing

From this research, we learned that vacuum glazing has an enormous potential in enhancing the sustainability performance. Unfortunately, the costs of the system hold back the application of vacuum glazing. Therefore more research has to be carried out of the exact performances of vacuum glazing and the production process.

Limit amount of glazing

The percentage of glass in the facade design of office building is still increasing. From this research can be learned that the higher the percentage of glass in the facade, the higher the sustainability performance. To reduce this effect, alternative design strategies have to be developed to limit the amount of glass without reducing the transparency of the building and incoming daylight.

Without louvres

One limitation of this research is that the design of the reference building includes louvres. Although it is commonly used in office buildings, it would be useful to know the influence of different parameters without the impact of the louvres.

Sun shading

Although the improvement accomplished with sun shading in this study appeared to be small, there is potential to significantly improve the sustainability performance is expected when lowering the MPG of sun shading. The available products in the database all have aluminium frames, meaning that a high quantity of material is used. More research should be conducted about concepts like facade screens or alternative sun shading systems.

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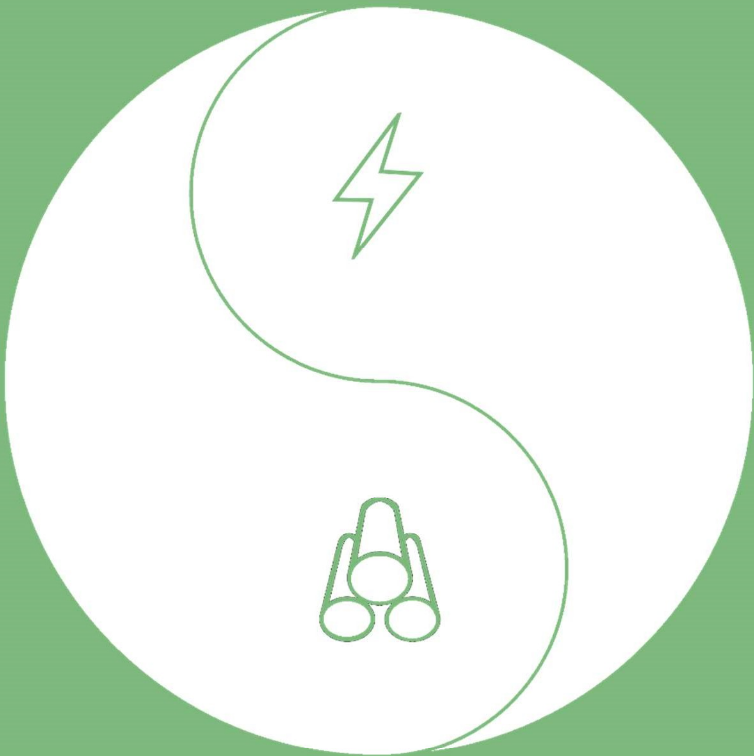

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APPENDICES

ALUMINIUM (50X175); POEDERCOATING

Milieu-informatie

NIBE Milieuklasse:

3b

Schaduwkosten: **€ 4,72**

Producteigenschappen:

Massa per FE	4,3	kg
Levensduur	75	jaar
U-waarde	1.330	W/m?K
Transportafstand naar fabriek	150	km

Afvalscenario:

Stort	5,6	%
Verbranding	18,7	%
Recycling	75,6	%
Hergebruik	0,1	%
Eigenprofiel	0,0	%

Omschrijving functionele eenheid

Een aluminium vliesgevel inclusief afdek- en klemlijst met een stramien van 1800x3600mm teruggerekend tot 1 m?. De stijl bestaat uit een een aluminium vliesgevelstijl van 50x175mm en een vliesgevelregel van 50x125mm. De aluminium vliesgevelprofielen en afdek- en klemlijsten zijn voorzien van een poedercoatingslaag met een dikte van 60mu. De vliesgevelstijlen en -regels zijn van kunststof koudebrug onderbrekingen voorzien waardoor ze een Uf-waarde behalen van 1,33 W/m?K.

Opvallende milieu-eigenschappen

Dit product valt in milieuklasse 3b en is daarmee milieutechnisch een aanvaardbare keuze. Het basisprofiel aluminium (47% secundair) veroorzaakt met 65,5% het grootste deel van de schaduwkosten, daarop volgen het basisprofiel Poedercoating Aluminium (7,6 m2/kg bij 60 mu) met 25,9% en het basisprofiel EPDM met 7,2% van de schaduwkosten.

De productiefase (A1-3) is verantwoordelijk voor 249,1% van de totale schaduwkosten gedurende de beschouwde periode van 75 jaar. Het transport naar de bouwplaats (A4) tijdens de constructiefase veroorzaakt 0,2% van de schaduwkosten. De constructie (A5) van het product veroorzaakt -4,4% van de schaduwkosten. In deze fase wordt het afval dat vrijkomt op de bouwplaats (o.a. verpakkingen en snijverlies) en processen die plaatsvinden bij constructie meegewogen. Er treden geen milieueffecten op die voortvloeien uit emissies naar lucht, bodem of water tijdens het gebruik (B1). Voor onderhoud (B2) treden geen milieueffecten op gedurende de beschouwde periode. Er vinden geen vervangingen (B3) plaats in de gebruiksfase en derhalve zijn er geen schaduwkosten voor dit onderdeel. Het repareren van het product (B4) tijdens de beschouwde periode veroorzaakt 2,7% van de totale schaduwkosten van het product. Er zijn geen schaduwkosten voor energieverbruik door het product (B6) om te kunnen functioneren in de beschouwde periode. Er zijn geen schaduwkosten voor waterverbruik door het product (B7) om te kunnen functioneren in de beschouwde periode. In de afvalfase van het product (C & D), exclusief het transport in deze fase (C2), worden -147,7% van de schaduwkosten veroorzaakt van wieg tot graf (bij recycling en re-use weer tot de wieg).Het transport in de afvalfase van het product (C2) veroorzaakt 0,1% van de schaduwkosten. De som van alle fases is 100%. Omdat er in de afvalfase een minwaarde behaald wordt, zijn de gesommeerde waarden van de andere fases meer dan 100%. Deze minwaarde wordt behaald doordat de recyclings-/hergebruikspotentie van het product in de afvalfase wordt toegerekend.

Milieucriteria

Emissies

br	broeikaseffect	1,87E+1	kg CO_2 eq
oz	ozonlaagaantasting	1,77E-6	kg CFC-11 eq
hu	humane toxiciteit	3,53E+1	kg 1,4 DB eq
aq	aquatische toxiciteit (zoet)	2,66E-1	kg 1,4 DB eq
aq	aquatische toxiciteit (zout)	1,54E+3	kg 1,4 DB eq
te	terrestische toxiciteit	1,91E-1	kg 1,4 DB eq
fo	fotochem. toxiciteit	8,20E-3	kg C_2H_4 eq
ve	verzuring	7,55E-2	kg SO_2 eq
eu	eutrofiëring (vermesting)	1,08E-2	kg PO_4 eq

Landgebruik

la	landgebruik	1,72E+0	PDF.m².jr

Hinder ten gevolge van

st	stank	2,86E+5	OTV m³
we	geluid door wegtransport	2,01E-5	DALY
pr	geluid door productie	4,30E+1	mbp
li	licht	4,42E+0	mbp
ca	kans op calamiteiten	3,24E+0	mbp

ALUMINIUM; PROFIEL; GECOAT

Milieu-informatie

NIBE Milieuklasse:

4a

Schaduwkosten: **€ 10,75**

Producteigenschappen:

Massa per FE	4,0	kg
Levensduur	40	jaar
Transportafstand naar fabriek	150	km

Afvalscenario:

Stort	5,0	%
Verbranding	32,0	%
Recycling	63,0	%
Hergebruik	0,1	%
Eigenprofiel	0,0	%

Omschrijving functionele eenheid

Gecoate aluminium geprofileerde platen toegepast als gevelbekleding. Het regelwerk en de benodigde bevestigingsmiddelen (verzinkt stalen nagels) zijn in de beoordeling meegenomen. Bij een dikte van 0,7 mm is per m? circa 2,75 kg aluminium nodig. De bevestigingsmiddelen en het regelwerk wegen gezamenlijk circa 1,2 kg.

Opvallende milieu-eigenschappen

Dit product valt in milieuklasse 4a en is daarmee milieutechnisch een minder goede keuze. Het basisprofiel gecoat aluminium (47% secundair) veroorzaakt met 99% het grootste deel van de schaduwkosten, daarop volgen het basisprofiel vuren schroten uit duurzame bosbouw met 1% en het basisprofiel licht constructiestaal (o.a. kozijnen, luchtkanalen en platen), c2 met 0% van de schaduwkosten.

De productiefase (A1-3) is verantwoordelijk voor 103% van de totale schaduwkosten gedurende de beschouwde periode van 75 jaar. Het transport naar de bouwplaats (A4) tijdens de constructiefase veroorzaakt 0,1% van de schaduwkosten. De constructie (A5) van het product veroorzaakt -2,4% van de schaduwkosten. In deze fase wordt het afval dat vrijkomt op de bouwplaats (o.a. verpakkingen en snijverlies) en processen die plaatsvinden bij constructie meegewogen. Er treden geen milieueffecten op die voortvloeien uit emissies naar lucht, bodem of water tijdens het gebruik (B1). Voor onderhoud (B2) treden geen milieueffecten op gedurende de beschouwde periode. Er vinden geen vervangingen (B3) plaats in de gebruiksfase en derhalve zijn er geen schaduwkosten voor dit onderdeel. Het repareren van het product (B4) tijdens de beschouwde periode veroorzaakt 46,7% van de totale schaduwkosten van het product. Er zijn geen schaduwkosten voor energieverbruik door het product (B6) om te kunnen functioneren in de beschouwde periode. Er zijn geen schaduwkosten voor waterverbruik door het product (B7) om te kunnen functioneren in de beschouwde periode. In de afvalfase van het product (C & D), exclusief het transport in deze fase (C2), worden -47,4% van de schaduwkosten veroorzaakt van wieg tot graf (bij recycling en re-use weer tot de wieg).Het transport in de afvalfase van het product (C2) veroorzaakt 0% van de schaduwkosten. De som van alle fases is 100%. Omdat er in de afvalfase een minwaarde behaald wordt, zijn de gesommeerde waarden van de andere fases meer dan 100%. Deze minwaarde wordt behaald doordat de recyclings-/hergebruikspotentie van het product in de afvalfase wordt toegerekend.

Milieucriteria

Emissies

br	broeikaseffect	2,67E+1	kg CO_2 eq
oz	ozonlaagaantasting	2,64E-6	kg CFC-11 eq
hu	humane toxiciteit	9,52E+1	kg 1,4 DB eq
aq	aquatische toxiciteit (zoet)	4,18E-1	kg 1,4 DB eq
aq	aquatische toxiciteit (zout)	2,07E+3	kg 1,4 DB eq
te	terrestische toxiciteit	3,02E-1	kg 1,4 DB eq
fo	fotochem. toxiciteit	1,18E-2	kg C_2H_4 eq
ve	verzuring	1,03E-1	kg SO_2 eq
eu	eutrofiëring (vermesting)	1,57E-2	kg PO_4 eq

Uitputting

bi	biotische grondstoffen	7,92E-5	mbp

Landgebruik

la	landgebruik	2,24E+0	PDF.m².jr

Hinder ten gevolge van

st	stank	5,06E+5	OTV m³
we	geluid door wegtransport	2,73E-5	DALY
pr	geluid door productie	6,00E+1	mbp
li	licht	5,62E+0	mbp
ca	kans op calamiteiten	4,64E+0	mbp

PUR/PIRSCHUIM PLATEN (PENTAAN GEBLAZEN); VERZINKT STALEN BEVESTIGING

Milieu-informatie

NIBE Milieuklasse:

1a

Schaduwkosten: **€ 1,26**

Producteigenschappen:

Massa per FE	6,2	kg
Levensduur	75	jaar
Rc-waarde	4.500	m?K/W
Transportafstand naar fabriek	150	km

Afvalscenario:

Stort	4,6	%
Verbranding	17,8	%
Recycling	15,3	%
Hergebruik	2,1	%
Eigenprofiel	0,0	%

Omschrijving functionele eenheid

PUR/PIR hardschuimen buitengevelisolatiesysteem toegepast tegen een kalkzandstenen binnenwandconstructie, de totale concstructie heeft een isolatiewaarde (Rc) van 3,5 m2K/W. Voor 1 m2 is: 2,835 kg PUR/PIR schuim benodigd. De verzinkt stalen beugels wegen per m2 ca. 1,08 kg.

Opvallende milieu-eigenschappen

Dit product valt in milieuklasse 1a en is daarmee milieutechnisch de beste keuze. Het basisprofiel NVPU cacheerlaag alulaminate PRODUCTIE C2 veroorzaakt met 55,5% het grootste deel van de schaduwkosten, daarop volgen het basisprofiel NVPU isolatiekern type I (R=1) PRODUCTIE C2 met 36,9% en het basisprofiel licht constructiestaal (o.a. kozijnen, luchtkanalen en platen), c2 met 6,5% van de schaduwkosten.

De productiefase (A1-3) is verantwoordelijk voor 93,7% van de totale schaduwkosten gedurende de beschouwde periode van 75 jaar. Het transport naar de bouwplaats (A4) tijdens de constructiefase veroorzaakt 1,2% van de schaduwkosten. De constructie (A5) van het product veroorzaakt 0,2% van de schaduwkosten. In deze fase wordt het afval dat vrijkomt op de bouwplaats (o.a. verpakkingen en snijverlies) en processen die plaatsvinden bij constructie meegewogen. Er treden geen milieueffecten op die voortvloeien uit emissies naar lucht, bodem of water tijdens het gebruik (B1). Voor onderhoud (B2) treden geen milieueffecten op gedurende de beschouwde periode. Er vinden geen vervangingen (B3) plaats in de gebruiksfase en derhalve zijn er geen schaduwkosten voor dit onderdeel. Er vinden geen reparaties (B4) plaats in de gebruiksfase en derhalve zijn er geen schaduwkosten voor dit onderdeel. Er zijn geen schaduwkosten voor energieverbruik door het product (B6) om te kunnen functioneren in de beschouwde periode. Er zijn geen schaduwkosten voor waterverbruik door het product (B7) om te kunnen functioneren in de beschouwde periode. In de afvalfase van het product (C & D), exclusief het transport in deze fase (C2), worden 3,9% van de schaduwkosten veroorzaakt van wieg tot graf (bij recycling en re-use weer tot de wieg).Het transport in de afvalfase van het product (C2) veroorzaakt 0,9% van de schaduwkosten.

Milieucriteria

Emissies

br	broeikaseffect	9,64E+0	kg CO_2 eq
oz	ozonlaagaantasting	5,36E-6	kg CFC-11 eq
hu	humane toxiciteit	6,78E+0	kg 1,4 DB eq
aq	aquatische toxiciteit (zoet)	5,79E-2	kg 1,4 DB eq
aq	aquatische toxiciteit (zout)	2,33E+2	kg 1,4 DB eq
te	terrestische toxiciteit	2,92E-2	kg 1,4 DB eq
fo	fotochem. toxiciteit	4,30E-3	kg C_2H_4 eq
ve	verzuring	2,25E-2	kg SO_2 eq
eu	eutrofiëring (vermesting)	3,15E-3	kg PO_4 eq

Uitputting

bi	biotische grondstoffen	3,02E-7	mbp
ab	abiotische grondstoffen	1,10E-2	kg Sb eq
en	energiedragers	5,28E-2	kg Sb eq

Landgebruik

la	landgebruik	5,61E-2	PDF.m².jr

Hinder ten gevolge van

st	stank	5,88E+4	OTV m³
we	geluid door wegtransport	1,06E-6	DALY
pr	geluid door productie	1,90E+1	mbp
li	licht	2,43E+0	mbp
ca	kans op calamiteiten	2,81E-1	mbp

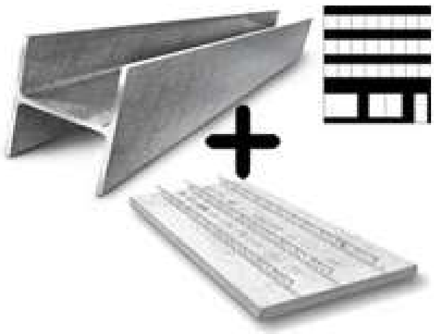
DRAAGCONSTR. STAAL & BREEDPLAATVLOER

Milieu-informatie

NIBE Milieuklasse:

1c

Schaduwkosten: **€ 37,12**



Producteigenschappen:

Massa per FE	1.398,0kg	
Levensduur	50	jaar
Transportafstand naar fabriek	150	km

Afvalscenario:

Stort	1,0	%
Verbranding	0,2	%
Recycling	96,9	%
Hergebruik	2,0	%
Eigenprofiel	0,0	%

Omschrijving functionele eenheid

De hoofddraagconstructie van een kantoor met een stramien van 7,2 m en 3 bouwlagen. Het bruto vloeroppervlak (BVO) van het kantoor is 3.000 m?. Het kantoor is gefundeerd met prefab betonpalen met een draagkracht van 2.000kN. De draagconstructie van het kantoor wordt uitgevoerd als staalconstructie, stabiliteit wordt verkregen d.m.v. windverbanden. De gehanteerde hoeveelheden zijn conform "Materiaalhoeveelheden Hoofddraagconstructie" van IMD raadgevende ingenieurs. De vloerconstructies worden uitgevoerd als Breedplaatvloer met een dikte van 230mm en de dakconstructie is uitgevoerd als Breedplaatvloer met een dikte van 220mm. De hoofddraagconstructie voldoet aan de sterkte-, geluids- en brandwerendheidseisen. De volledige materialisatie is teruggerekend naar 1 m? BVO.

Opvallende milieu-eigenschappen

Dit product valt in milieuklasse 1c en is daarmee milieutechnisch een zeer goede keuze. Het basisprofiel Prefab beton C20/25 XC2, 0% puingranulaat, CEM I veroorzaakt met 73,5% het grootste deel van de schaduwkosten, daarop volgen het basisprofiel middelzwaar constructiestaal (o.a. geleiderails), c2 met 12,8% en het basisprofiel zwaar constructiestaal (o.a. balken, profielen, liggers), c2 met 7,1% van de schaduwkosten.

De productiefase (A1-3) is verantwoordelijk voor 69% van de totale schaduwkosten gedurende de beschouwde periode van 75 jaar. Het transport naar de bouwplaats (A4) tijdens de constructiefase veroorzaakt 9,6% van de schaduwkosten. De constructie (A5) van het product veroorzaakt -0,4% van de schaduwkosten. In deze fase wordt het afval dat vrijkomt op de bouwplaats (o.a. verpakkingen en snijverlies) en processen die plaatsvinden bij constructie meegewogen. Er treden geen milieueffecten op die voortvloeien uit emissies naar lucht, bodem of water tijdens het gebruik (B1). Voor onderhoud (B2) treden geen milieueffecten op gedurende de beschouwde periode. Er vinden geen vervangingen (B3) plaats in de gebruiksfase en derhalve zijn er geen schaduwkosten voor dit onderdeel. Het repareren van het product (B4) tijdens de beschouwde periode veroorzaakt 33,3% van de totale schaduwkosten van het product. Er zijn geen schaduwkosten voor energieverbruik door het product (B6) om te kunnen functioneren in de beschouwde periode. Er zijn geen schaduwkosten voor waterverbruik door het product (B7) om te kunnen functioneren in de beschouwde periode. In de afvalfase van het product (C & D), exclusief het transport in deze fase (C2), worden -14,3% van de schaduwkosten veroorzaakt van wieg tot graf (bij recycling en re-use weer tot de wieg).Het transport in de afvalfase van het product (C2) veroorzaakt 2,8% van de schaduwkosten. De som van alle fases is 100%. Omdat er in de afvalfase een minwaarde behaald wordt, zijn de gesommeerde waarden van de andere fases meer dan 100%. Deze minwaarde wordt behaald doordat de recyclings-/hergebruikspotentie van het product in de afvalfase wordt toegerekend.

* Prefab beton wordt veelal vervaardigd met CEM I als bindmiddel, i.v.m. de benodigde (snelle) droogtijd. Het van klinker gemaakte CEM I heeft een hogere milieulast dan andere CEM soorten.

Milieucriteria

Emissies

br	broeikaseffect	4,21E+2	kg CO_2 eq
oz	ozonlaagaantasting	1,85E-5	kg CFC-11 eq
hu	humane toxiciteit	5,80E+1	kg 1,4 DB eq
aq	aquatische toxiciteit (zoet)	1,66E+0	kg 1,4 DB eq
aq	aquatische toxiciteit (zout)	8,70E+3	kg 1,4 DB eq
te	terrestische toxiciteit	7,66E-1	kg 1,4 DB eq
fo	fotochem. toxiciteit	1,60E-1	kg C_2H_4 eq
ve	verzuring	1,71E+0	kg SO_2 eq
eu	eutrofiëring (vermesting)	2,75E-1	kg PO_4 eq

Uitputting

bi	biotische grondstoffen	7,18E-5	mbp
ab	abiotische grondstoffen	4,34E-4	kg Sb eq
en	energiedragers	1,46E+0	kg Sb eq

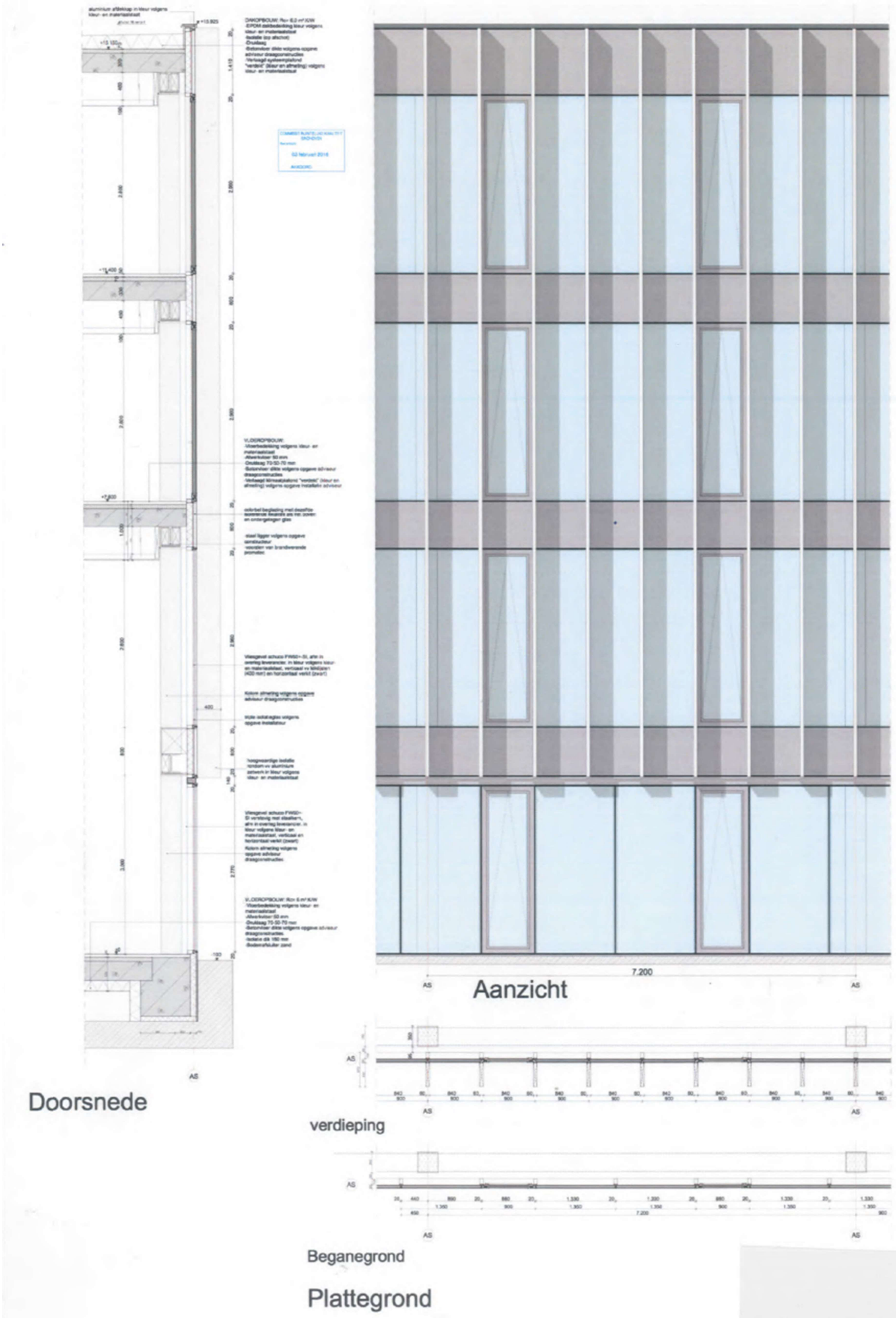
Landgebruik

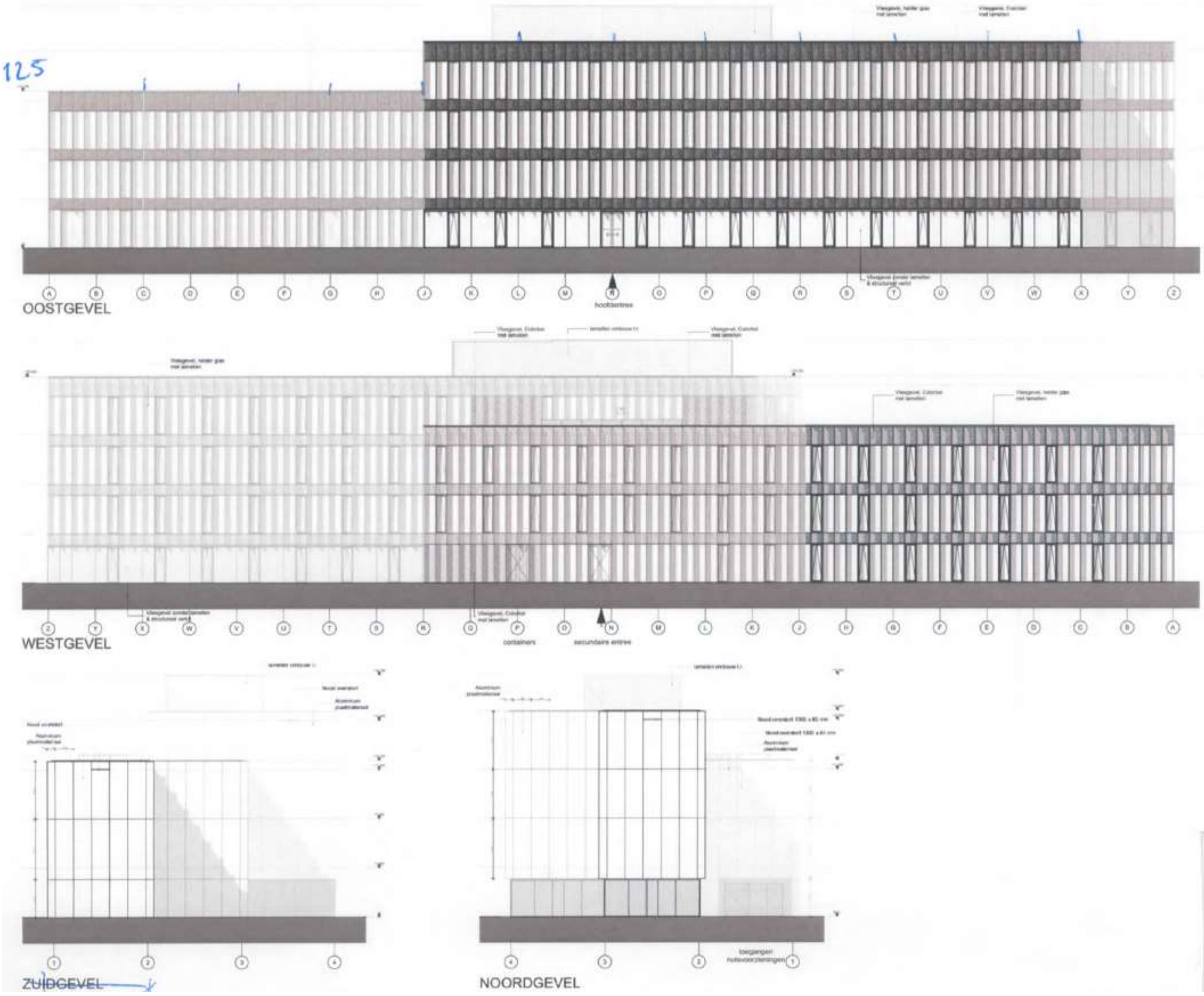
la	landgebruik	2,13E+1	PDF.m².jr

Hinder ten gevolge van

st	stank	4,62E+5	OTV m³
we	geluid door wegtransport	1,44E-4	DALY
pr	geluid door productie	1,35E+3	mbp
li	licht	5,36E+0	mbp
ca	kans op calamiteiten	4,33E+0	mbp

APPENDIX B: DRAWINGS REFERENCE OFFICE




125
OOSTGEVEL
hoofdentree
WESTGEVEL
containers
secundaire entree
ZUIDGEVEL
NOORDGEVEL

APPENDIX C: EPG CALCULATION REFERENCE OFFICE

Uniec 2.2

STUDIEBEREKENING

- Reference office DGBC standard
1

0,24

Algemene gegevens

projectomschrijving	*Reference office DGBC standaard*
variant	*1*
straat / huisnummer / toevoeging	
postcode / plaats	*5656AG Eindhoven*
eigendom	*Onbekend*
bouwjaar	*2017*
renovatiejaar	
categorie	*Energieprestatie Utiliteitsbouw*
gebouwtype	*meerlaags gebouw*
datum	*01-07-[illegible]*
opmerkingen	

Indeling gebouw

Eigenschappen rekenzones

type rekenzone	omschrijving	massa vloer	type plafond
verwarmde zone	verwarmde zone	> 400 kg/m²	gesloten plafond

Interne warmtecapaciteit volgens bijlage H *nee*

Gebruiksfuncties per rekenzone verwarmde zone

gebruiksfunctie	A_g [m²]	open verbinding	80% regel	aangesloten op gem. ruimte	$\theta_{int;set;H}$ [°]	$q_{g;spec}$ [dm³/sm²]	EPC eis
kantoorfunctie	3.588,00	nee	nee	n.v.t.	20,00	1,11	0,80
bijeenkomstfunctie overig	524,00	nee	nee	n.v.t.	20,00	1,71	1,10
bijeenkomstfunctie kinderopvang	12[illegible]	nee	nee	n.v.t.	20,00	2,78	1,10

Infiltratie

meetwaarde voor infiltratie $q_{v;10;spec}$	*ja*
lengte van het gebouw	*86,40 m*
breedte van het gebouw	*21,60 m*
hoogte van het gebouw	*15,20 m*

Eigenschappen infiltratie

rekenzone	positie	dak en/of geveltype	$q_{v;10;spec}$ [dm³/s per m²]
verwarmde zone	gehele gebouw	standaard geveltype	0,39 (meetwaarde)

Open verbrandingstoestellen

Het gebouw bevat geen open verbrandingstoestellen.

Bouwkundige transmissiegegevens

Transmissiegegevens rekenzone verwarmde zone							
constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
dak - buitenlucht, HOR, dak - 1.346,0 m² - 0°							
dak	1.346,00	6,00				minimale belem.	
noordgevel - buitenlucht, N - 114,0 m² - 90°							
gevel	107,00	4,50				minimale belem.	
deur	7,00		2,00	0,00	nee	minimale belem.	
oostgevel - buitenlucht, O - 1.260,0 m² - 90°							
gevel	175,00	4,50				minimale belem.	
glas	1.085,00		0,90	0,30	nee	minimale belem.	
zuidgevel - buitenlucht, Z - 114,0 m² - 90°							
gevel	114,00	4,50				minimale belem.	
westgevel - buitenlucht, W - 1.260,0 m² - 90°							
gevel	170,00	4,50				minimale belem.	
glas	1.085,00		0,90	0,30	nee	minimale belem.	
deur	5,00		2,00	0,00	nee	minimale belem.	
vloer - vloer op/boven mv; boven kruipruimte - 1.346,0 m							
vloer	1.346,00	5,00					

De lineaire warmteverliezen zijn berekend volgens de forfaitaire methode uit paragraaf 5.1.3. van NEN 1068.

Overige kenmerken vloerconstructies (inclusief evt. kruipruimten en onverwarmde kelders)

vloer - vloer op/boven mv; boven kruipruimte

hoogte bovenkant vloer boven maaiveld (h)	*1,00 m*
omtrek van het vloerveld (P)	*213,00 m*
grootste dikte v.d. gevels/wanden ter hoogte v.d. bk vloer ($d_{bw;v}$)	*0,50 m*
gem. vert. afstand tussen MV en bk kelder-, kruipruimtevloer (z_o)	*1,00 m*
kruipruimteventilatie (ε)	*0,0012 m²/m¹*
warmteweerstand v.d. kelder-, kruipruimtewanden boven mv (R_{xw})	*5,00 m²K/W*
warmteweerstand v.d. kelder-, kruipruimtewanden onder mv ($R_{bw;o}$)	*4,50 m²K/W*
warmteweerstand v.d. kelder-, kruipruimtevloer (R_{bf})	*1,00 m²K/W*
grootste dikte v.d. wand t.h.v. de bk kelder-, kruipruimtevloer ($d_{bw;o}$)	*1,00 m*

Verwarmingsystemen

verwarming

Opwekking

type opwekker	*elektrische warmtepomp*
bron warmtepomp	*grondwater/aquifer*
ontwerpaanvoertemperatuur	*θsup ≤ 30°*
vermogen warmtepomp	*185,00 kW*
β-factor warmtepomp	*2,41*
aantal opwekkers	*1*
type bijverwarming	*externe warmtelevering*
transmissieverlies verwarmingssysteem - januari (H_T)	*3.101 W/K*
warmtebehoefte verwarmingssysteem ($Q_{H;nd;an}$)	*306.700 MJ*
hoeveelheid energie t.b.v. verwarming per toestel ($Q_{H;dis;nren;an}$)	*306.700 MJ*
opwekkingsrendement - warmtepomp ($\eta_{H;gen}$)	*5,000*
opwekkingsrendement - bijverwarming ($\eta_{H;gen}$)	*1,000*

Kenmerken afgiftesysteem verwarming

Type warmteafgifte					
type warmteafgifte	positie	hoogte	R_c	$\theta_{em;avg}$	$\eta_{H;em}$
vloer- en/of wandverwarming en/of betonkernactivering	binnenvloer of binnenwand	< 8 m	n.v.t.	n.v.t.	1,00

afgifterendement ($\eta_{H;em}$)	*1,000*

Kenmerken distributiesysteem verwarming

warmtetransport door	*n.v.t. (lokaal systeem)*
koeltransport door	*n.v.t. (lokaal systeem of geen koeling)*
geïsoleerde leidingen en kanalen	*ja*
distributierendement ($\eta_{H;dis}$)	*1,000*

Hulpenergie verwarming

hoofdcirculatiepomp aanwezig	*ja*
hoofdcirculatiepomp voorzien van pompregeling	*ja*
werkelijk vermogen hoofdcirculatiepomp bekend	*ja*
werkelijk vermogen hoofdcirculatiepomp	*1.170,0 W*
aanvullende circulatiepomp aanwezig	*ja*
werkelijk vermogen aanvullende circulatiepomp bekend	*ja*
werkelijk vermogen aanvullende circulatiepomp	*820,0 W*
aanvullende circulatiepomp voorzien van pompregeling	*ja*
rekenzones voorzien van aanvullende circulatiepomp	*verwarmde zone*

Aangesloten rekenzones

verwarmde zone

Warmtapwatersystemen

warmtapwater

Opwekking

warmtapwaterbereidingsysteem	*direct verwarmde warmwatervoorraadvat(en)*

forfaitair of productspecifiek	*productspecifiek - eigen verklaring*
type opwekker	*kwaliteitsverklaring excl. hulpenergie - overige (elektrisch)*
hoeveelheid energie t.b.v. warmtapwater per toestel ($Q_{W;dis;nren;an}$)	*35.897 MJ*
opwekkingsrendement	*0,500*
opwekkingstoestel tevens gebruikt voor verwarming	*nee*
opwekkingstoestel zonder hulpenergie	*nee*

Kenmerken tapwatersysteem

gebruiksoppervlakte aangesloten op systeem	*4.235,00 m²*
gemiddelde lengte uittapleidingen	*> 3 meter*
afgifterendement warmtapwater ($\eta_{W;em}$)	*0,800*

Kenmerken distributiesysteem tapwater

individuele afleverset	*ja*
afleverset aangesloten op	*LT*
circulatieleiding	*nee*

Douchewarmteterugwinning

douchewarmteterugwinning	*nee*

Zonneboiler

zonneboiler	*ja*
zonneboiler(combi) ten behoeve van:	*warmtapwater*
collector	*methode b volgens NEN 7120 bijlage I*
warmteopslagvat	*in onverwarmde ruimte*
type naverwarming	*electrisch op nachtstroom*
leidingen tussen warmteopslag en collectoren	*ongeïsoleerd*
zonnekeur	*nee*
collectortype	*vlakke plaat*
afdekking collector	*geen*
spectraal selectief	*nee*
PVT systeem	*geen PVT systeem*
thermosifon of ICS systeem	*ja*

Zonneboiler eigenschappen

oriëntatie	helling [°]	A_{col} [m²]	V_{sto} [dm³]	V_{bu} [dm³]	$P_{defrost}$ [W]	beschaduwing
Z	20	[illegible]00	500	200	10	minimale belemmering

Ventilatie

ventilatie 1

Ventilatiesysteem

ventilatiesysteem	*Dc. mechanische toe- en afvoer - centraal*
systeemvariant	*D5a CO2-sturing met 2 of meer zones*
luchtvolumestroomfactor voor warmte- en koudebehoefte (f_{sys})	*1,00*
correctiefactor regelsysteem voor warmte- en koudebehoefte (f_{reg})	*0,67*

Kenmerken ventilatiesysteem

centrale luchtbehandelingskast aanwezig	*nee*

werkelijk geïnstalleerde ventilatiecapaciteit bekend	*nee*
terugregeling / recirculatie	*geen terugregeling / recirculatie*
luchtdichtheidsklasse ventilatiekanalen	*onbekend*

Passieve koeling

max. benutting geïnstal. ventilatiecapaciteit voor koudebehoefte	*ja*
max. benutting geïnstal. spuicapaciteit voor koudebehoefte	*ja*
spuivoorziening	*te openen ramen*

Kenmerken warmteterugwinning

rendement warmteterugwinning forfaitair	*langzaam roterende of intermitterende warmtewisselaar - 70%*
rendement warmteterugwinning inclusief dissipatie	*ja*
fractie lucht via bypass	*1,00*
toevoerkanaal tussen buiten en WTW toestel	*geïsoleerd kanaal*
type isolatie toevoerkanaal tussen buiten en WTW toestel bekend	*ja*
dikte isolatie toevoerkanaal	*0,020 m*
warmtedoorgangscoëfficiënt (λ) isolatie toevoerkanaal	*0,080 W/mK*
lengte toevoerkanaal tussen buiten en WTW toestel (L_{bu})	*1,0m*

Kenmerken ventilatoren

nominaal vermogen ventilator(en) forfaitair	*ja*
type ventilatoren (vermogen forfaitair)	*gelijkstroom*
extra circulatie op ruimteniveau	*nee*
ventilatoren met constant-volumeregeling	*nee*

Aangesloten rekenzones

verwarmde zone

Koeling

koeling 1

Kenmerken opwekker

type opwekker	*koudeopslag / bodemkoeling (zonder inzet koelmachine)*
koudebehoefte koelsysteem ($Q_{C;nd}$)	*435.695 MJ*
opwekkingsrendement ($\eta_{C;gen}$)	*12,000*

Kenmerken koelsysteem

koeltransport ingevoerd bij verwarmingssysteem	*verwarming*
distributierendement ($\eta_{C;dis}$)	*1,00*

Hulpenergie koeling

koude direct afgegeven aan binnenlucht of LBK	*nee*
pompmotoren in gekoeld water circuits automatische toerenregeling	*ja*
koudeopwekker met toerenregeling (ventilatoren en pompen)	*ja*
koudeopwekker opwekkingsrendement inclusief standby hulpenergie	*nee*
koudeopwekker tevens gebruikt voor verwarming	*nee*

Aangesloten rekenzones

verwarmde zone

Zonnestroom

zonnestroom 1

piekvermogen (Wp) per m² *190 Wp/m² bepaald volgens NEN-EN-IEC 60904-1*

Zonnestroom eigenschappen				
ventilatie	A_{PV} [m²]	oriëntatie	helling [°]	beschaduwing
sterk geventileerd - vrijstaand	183,68	O	10	minimale belemmering
sterk geventileerd - vrijstaand	137,76	W	10	minimale belemmering
sterk geventileerd - vrijstaand	216,48	Z	10	minimale belemmering

Verlichting

verlichting verwarmde zone

Verlichtingssysteem

verlichtingsvermogen forfaitair *nee*
oppervlakte daglichtsector (A_{dayl}) forfaitair *nee*

Kenmerken verlichtingssysteem

aanwezigheidsdetectie > 70% van rekenzone *ja*
armatuurafzuiging > 70% van verlichtingsvermogen *nee*

Eigenschappen verlichtingssysteem				
regeling	$P_{n;spec}$ [W/m²]	A_{zone} [m²]	A_{dayl} [m²]	F_D
veegpulsschakeling icm daglichtschakeling	6,0	4.235,00	2.500,00	0,61

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	157.030 MJ
hulpenergie		68.703 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	103.705 MJ
hulpenergie		1.063 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	92.94[illegible] MJ
hulpenergie		39.837 MJ
zomercomfort	$E_{SC;P}$	[illegible] MJ
bevochtiging	$E_{hum;P}$	0 MJ
ventilatoren	$E_{V;P}$	1[illegible]2.33[illegible] MJ
verlichting	$E_{L;P}$	[illegible].896 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte & verbruikte elektriciteit	$E_{P;pr;us;el}$	77[illegible].185 MJ
in het gebied opgewekte elektriciteit	$E_{P;pr;dei;el}$	0 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	4.235,00 m²
totale verliesoppervlakte	A_{ls}	5.036,20 m²

Elektriciteitsgebruik	
gebouwgebonden installaties	115.724 kWh
niet-gebouwgebonden apparatuur (stelpost)	131.391 kWh
op eigen perceel opgewekte & verbruikte elektriciteit	84.004 kWh
geëxporteerde electriciteit	0 kWh
TOTAAL	163.111 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	17.917 kg

Energieprestatie		
specifieke energieprestatie	EP	69 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	292.329 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	1.237.212 MJ
E_{ptot} / $E_{P;adm;tot;nb}$ (Bouwbesluit)		0,24 -
E_{ptot} / $E_{P;adm;tot;nb}$ (energielabel)		0,17 -
energielabel nieuwbouw utiliteit		A++++

Onderstaande BENG Indicatoren zijn berekend conform de Handreiking BENG gebaseerd op de NEN 7120. Vanaf 20 november 2018 is het duidelijk dat deze indicatoren en de voorlopige BENG eisen uit 2015 achterhaald zijn. Zie ons artikel `Nieuwe BENG eisen bekend`. Wij raden ten sterkste af om met onderstaande informatie te rekenen en kunnen geen helpdesk vragen over deze eisen beantwoorden, aangezien wij ons richten op de BENG eisen conform NTA 8800 en de bijbehorende software Uniec 3. De enige reden dat wij deze resultaten nog tonen is om gebruikers tegemoet te komen die voor 20 november 2018 met deze getallen hebben gerekend en het resultaat willen inzien.

BENG indicatoren	
energiebehoefte	56,2 kWh/m²
primair energiegebruik	19,2 kWh/m²
aandeel hernieuwbare energie	[illegible] %

In de berekening wordt gebruik gemaakt van het principe met een getrapte EPC eis conform Bouwbesluit 2012 artikel 5.2 lid 3.
Het gebouw voldoet aan de 1e trap eis (1,33 x BB eis) inzake energieprestatie uit het Bouwbesluit 2012.
Bij deze berekening behoort tevens een berekening van de 2e trap eis.

Uniec 2.2 is gebaseerd op NEN7120;2011 "Energieprestatie van gebouwen" (inclusief het Nader Voorschrift) en NEN 8088-1 "Ventilatie en luchtdoorlatendheid van gebouwen" inclusief alle wettelijk van kracht zijnde correctiebladen.

Alle bovenstaande energiegebruiken zijn genormeerde energiegebruiken gebaseerd op een standaard klimaatjaar en een standaard gebruikersgedrag. Het werkelijke energiegebruik zal afwijken van het genormeerde energiegebruik. Aan de berekende energiegebruiken kunnen geen rechten ontleend worden.

Rapportage Freetool MRPI Milieuprestatie Gebouw

In deze rapportage zijn de resultaten en de invoer opgenomen van de milieuprestatieberekening gebouw van Reference office DGBC. De resultaten zijn verdeeld naar de verplichte milieuprestatieberekening voor het bouwbesluit op basis van afdeling 5.2 en naar de MPG score. Tot slot is een verantwoording voor de berekening opgenomen.

Algemene gegevens

Naam project:	Reference office DGBC
Organisatie:	TNO
Gebruiksfunctie:	Kantoorgebouw
Bvo:	4567 m2
Levensduur:	50 jaar
Datum rapportage:	07-05-2019

Resultaat bouwbesluit

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. In de onderstaande tabel zijn de relevante resultaten opgenomen.

Milieu-impact	berekende waarde	eenheid
Uitputting abiotische grondstoffen (excl. fossiel)	0,001	kg Sb eq./ m2 BVO*jaar
Uitputting fossiele energiedragers	0,052	kg Sb eq./ m2 BVO*jaar
Klimaatverandering (100 jaar)	9,75	kg CO2 eq./ m2 BVO*jaar

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Resultaat MPG-score

In bijlage I is een overzicht opgenomen van de geselecteerde producten inclusief hoeveelheden en eventuele dimensies van het product. De MPG-score van Reference office DGBC is 1,12 € / m2 BVO. In de onderstaande tabel is dit resultaat weergegeven naar de verschillende bouwdelen.

Bouwdeel	Resultaat
Fundering	7%
Vloeren	18,8%
Draagconstructie	5,3%
Gevels	36%
Daken	6,7%
Installaties	22,4%
Inbouw	3,9%

De berekende resultaten zijn direct gekoppeld aan de in bijlage I opgenomen producten, een afwijkende materialisatie of productkeuze heeft invloed op de berekening. Indien in het verdere ontwerp- en bouwproces andere materiaalkeuzes worden gemaakt dient de milieuprestatie opnieuw berekend te worden.

Verantwoording

Deze berekening is gemaakt met de Freetool MRPI-MPG, er is voor de berekening gebruik gemaakt van versie 2.3 van de productendatabase van de nationale milieudatabase, hieraan is versie 1.1.6 van de basisprofielendatabase gekoppeld.

milieu relevante product informatie

Rapportage Freetool MRPI Milieuprestatie Gebouw

Bijlage I, invoer berekening

ongetoetst

getoetst

Fundering

Bodemvoorzieningen		
Grondaanvullingen	Zand	402,3 m3
Fundering		
Funderingspalen	Heipaal; beton, prefab; AB-FAB [530,530]	2000,9 m1

Vloeren

Vloeren, verdieping		
Vloeren	Betonhuis; druklaag breedplaatvloer; betonmortel C20/25,CEMIII,20%betongranulaat CEMIII; incl. wapening [190]	4156 m2
Vloeren	Breedplaat, excl. druklaag, 60mm; prefab beton; AB-FAB	4156 m2
Dekvloeren	Zandcement [120]	4156 m2

Draagconstructie

Hoofddraagconstructies		
Dragende wanden, massief	Beton, prefab, utiliteitsbouw; AB-FAB [200]	921,7 m2
Constructies (kg)	Staal zwaar constructiestaal o.a. balken, profielen en liggers	176730 kg

Gevels

Gevels, dicht		
Elementgevels	Aluminium, gecoat	2582 m2
Vliesgevels	Aluminium, gecoat	2582 m2
Isolatielagen	NVPU; PU plaat; gecacheerd, alulaminaat [6]	934 m2
Bekledingen	Aluminium; profielplaat+stalen profielen; gemoffeld; [1.3]	2550 m2

Gevels, open		
Beglazing	Drievoudig glas; droog beglaasd [16]	2582 m2

Daken

Daken, plat		
Daken	Betonhuis; druklaag breedplaatvloer; betonmortelC20/25,CEMIII; incl. wapening [190]	1341 m2
Daken	Breedplaat, excl. druklaag, 60mm; prefab beton; AB-FAB	1341 m2
Isolatielagen	NVPU; PU plaat; gecacheerd, aluminium [3.5]	1341 m2
Bedekkingen	EPDM, sbs cachering; verkleefd	1341 m2
Verlaagde plafonds	Gipskartonplafond, dubbel raster, enkel beplaat zonder isolatie (NBVG)	161 m2
Verlaagde plafonds	Steenwol MWA 2012, geperst; d:20mm; +profielen,staal	2635 m2

Installaties

Warmtelevering		
Warmteopwekkingsinstallaties U-bouw	Warmtepomp Brine-water, 65 w/m2	4567 m2gbo
Warmteafgiftesystemen	Klimaatplafond gecombineerd warmte en koude; staalplafond+leidingen	4567 m2gbo
Warmteafgiftesystemen	Vloerverwarming; leidingen:polybuteen+toebehoren	4567 m2gbo
Elektrische installatie		
Elektricteitsleidingen	Geisoleerde installatiedraad + mantelbuis:pvc	4567 m2gbo
Elektriciteitsopwekkingsystemen	PV,CIS; plat dak; incl. inverter+steun+kabels	524 m2
Luchtbehandeling		
Luchtbehandelingssystemen	VLA LBK; balans, 0-4.000m3/h, koeling+verwarming+warmtewiel; U-bouw	1 p
Water- en gasdistributie		
Waterleidingen	Koper (leiding +mantelbuis)	4567 m2gbo
Afvoeren		
Binnenrioleringen	Pvc; gerecycled; leiding	4567 m2gbo
Hemelwaterafvoeren	Polyetheen; diameter:80mm; d:1.8mm	80 m1

Inbouw

Binnenwanden		
Niet dragende wanden, systeem, bekledingen	Aluminium plaat [0.7]	554 m2
Niet dragende wanden, verplaatsbaar	Staal frame element; glas paneel	332 m2

Niet dragende wanden, verplaatsbaar	Staalframe element; spaanplaat paneel; duurzame bosbouw	854 m2
Afwerklagen	MOSA Keramische wandtegels; geglazuurd/geplaatst/gevoegd	642 m2

Binnenwandopeningen

Binnendeuren	Honingraat; geschilderd:alkyd	100 p
Binnendeuren	Hout; geschilderd:alkyd	21 p
Binnendorpels	Natuursteen [20,100]	14 m1

Trappen en liften

Liftcabines	Staal; personenlift; gemoffeld	1 p
Liftinstallaties	Staal; hefconstructie+contragewicht; 1 bouwlaag	4 p

Vaste voorzieningen

Keukenkasten	Spaanplaat; kunststoflaag	13,4 m1
Toiletten	Wandcloset + fontein, porselein; incl. kunststof reservoir	38 p
Wasvoorzieningen	Keramiek; wastafel	24 p

APPENDIX E: CALCULATION WINDLOADS SCENARIO 3

(NEN-EN 1991-1-4+A1+C2:2011 nl, 2011)

Berekening qp volgens EN1991-1-4 en NB

Waardes en coëfficiënten zijn afkomstig uit de Eurocodes en nationale bijlagen, of worden berekend aan de hand van deze normen. Deze waarden niet wijzigen zonder overleg

1.	opgave coëfficiënten				
1.1	cdir	cdir	1,0		1991 par 4.2 note 2
1.2	cseason	cseason	1,0		1991 par 4.2 note 3
1.3	vb,0		vb,0		NB par 4.2 tabel NB1
		gebied 1	29,5	m/s	
		gebied 2	27,0	m/s	
		gebied 3	24,5	m/s	
1.4	t.b.v. cprob		K	n	NB par 4.2 tabel NB2
		gebied 1	0,2	0,5	
		gebied 2	0,234	0,5	
		gebied 3	0,281	0,5	
1.5.1	referentietijd		50	jaar	
1.5.2	p= 1/referentietijd	1/50=	0,02		
1.6	orografie factor co(z)	co(z)	1,0		VMRG Gevels en Statica par. 2.1 gebaseerd op vlak terrein (Φ<0,05)
1.7	turbulentiefactor ki	ki	1,0		1991 par 4.4
1.8	luchtdichtheid ρ	ρ	1,25	kg/m3	1991 par 4.5 note 2
1.9	ruwheidslengte z0				
		zone : omschrijving	z0		nb tabel 4.1
1.9.1		0: kustligging	0,005		
1.9.2		II: onbebouwd	0,200		
1.9.3		III: bebouwd	0,500		
1.10	minimum hoogte zmin				
		zone : omschrijving	zmin		nb tabel 4.1
1.10.1		0: kustligging	1		
1.10.2		II: onbebouwd	4		
1.10.3		III: bebouwd	7		

referentieperiode 50 jaar

Fysische waarden				
Aluminium	E mod	70.000	N/mm2	naam eal
	Buigspanning s:	160	N/mm2	naam sigal

2.	Berekeningen (extra) benodigde coëficënten en startwaardes			
2.1	vb	vb=vb,0*cdir*cseason=	vb	
2.1.1		gebied 1 29,5*1*1=	29,50	m/s
2.1.2		gebied 2 27*1*1=	27,00	m/s
2.1.3		gebied 3 24,5*1*1=	24,50	m/s

2.2 cprob

$$cprob = \left[\frac{1 - K * ln(-ln(1-p))}{1 - K * ln(-ln(0{,}98))}\right]^n$$ met

K en n volgens 1.4
p volgens 1.5.2

			cprob
2.2.1	cprob	gebied 1	1,0000
2.2.2		gebied 2	1,0000
2.2.3		gebied 3	1,0000

1-K*ln(-ln(1-p))	1-K*ln(-ln(0,98))
1,780387732	1,780387732
1,913053646	1,913053646
2,096444763	2,096444763

2.3	vbgem	vbgem=vb*cprob	vbgem	
2.3.1		gebied 1	29,50	m/s
2.3.2		gebied 2	27,00	m/s
2.3.3		gebied 3	24,50	m/s

gemiddelde basis windsnelheid (rekenwaarde)

2.4 berekening gemiddelde wind vm(z)

$$vm(z) = cr(z) * co(z) * vbgem$$

met:

co(z) volgens 1.6
vbgem volgens 2.3.1, 2.3.2, 2.3.3

met:
cr(z)=ruwheidsfactor, te berekenen — cr(z) = kr*ln(z/z0)
kr= terreinfactor, te berekenen — kr=0,19*(z0/0,05)^0,07
z0=ruwheidslengte volgens 1.9.1, 1.9.2, 1.9.3
z=hoogte (gebouwhoogte h in de overige berekeninegn)
z mag niet minder zijn dan zmin volgens 1.10.1, 1.10.2, 1.10.3

2.4.1 kr

$$kr = 0{,}19 * \left(\frac{z0}{0{,}05}\right)^{0{,}07}$$

	zone : omschrijving	kr
2.4.1.1	0: kustligging	0,162
2.4.1.2	II: onbebouwd	0,209
2.4.1.3	III: bebouwd	0,223

2.4.2 cr

$$cr(z) = kr * \ln\left(\frac{z}{z0}\right)$$

z=h= 15,00 m, zie voorblad

z<zmin?

	zone : omschrijving	check	z=
2.4.2.1	0: kustligging	FALSE	15,00
2.4.2.2	II: onbebouwd	FALSE	15,00
2.4.2.3	III: bebouwd	FALSE	15,00

cr(z)

	zone : omschrijving	cr(z)
2.4.2.4	0: kustligging	1,297
2.4.2.5	II: onbebouwd	0,902
2.4.2.6	III: bebouwd	0,758

vm(z)

	zone : omschrijving	gebied 1				gebied 2		gebied 3		
2.4.2.7	0: kustligging	1,297*1*29,5=	38,3			1,297*1*27=	35,0			m/s
2.4.2.8	II: onbebouwd	0,902*1*29,5=	26,6			0,902*1*27=	24,4	0,902*1*24,5=	22,1	m/s
2.4.2.9	III: bebouwd	0,758*1*29,5=	22,4			0,758*1*27=	20,5	0,758*1*24,5=	18,6	m/s

2.5 bepaling windturbulentie intensiteit Iv(z)

2.5.1 bepaling σv

$$\sigma v = kr * vbgem * ki$$ met

kr volgens 2.4,1,1, 2.4,1.2, 2.4.1.3
ki volgens 1.7

σv

	zone : omschrijving	gebied 1				gebied 2		gebied 3	
2.5.1.1	0: kustligging	0,162*29,5*1=	4,7790			0,162*27*1=	4,3740		
2.5.1.2	II: onbebouwd	0,209*29,5*1=	6,1655			0,209*27*1=	5,6430	0,209*24,5*1=	5,1205
2.5.1.3	III: bebouwd	0,223*29,5*1=	6,5785			0,223*27*1=	6,0210	0,223*24,5*1=	5,4635

2.5.2 Iv(z)

$$Iv(z) = \frac{\sigma v}{vm(z)}$$ met

σv volgens 2.5.1.1, 2.5.1.2, 2.5.1.3
vm(z) =volgens 2.4.2.7, 2.4.2.8, 2.4.2.9

Iv(z)

	zone : omschrijving	gebied 1				gebied 2		gebied 3	
2.5.2.1	0: kustligging	4,779/38,3=	0,1248			4,374/35=	0,1250		
2.5.2.2	II: onbebouwd	6,1655/26,6=	0,2318			5,643/24,4=	0,2313	5,1205/22,1=	0,2317
2.5.2.3	III: bebouwd	6,5785/22,4=	0,2937			6,021/20,5=	0,2937	5,4635/18,6=	0,2937

3 Berekening qp

3.1 qp

$$qp(z) = [1 + 7 * Iv(z)] * \frac{1}{2} * \rho * vm(z)^2$$ met

Iv(z) volgens 2.5.2.1, 2.5.2.2, 2.5.2.3
ρ volgens 1.8
vm(z) volgens 2.4.2.7,2.4.2.8, 2.4.2.9

	zone : omschrijving	gebied 1				gebied 2		gebied 3		
3.1.1	0: kustligging	[1+7*0,1248]*½*1,25*38,3²=	1.718			[1+7*0,125]*½*1,25*35²=	1.436			N/m2
3.1.2	II: onbebouwd	[1+7*0,2318]*½*1,25*26,6²=	1.160			[1+7*0,2313]*½*1,25*24,4²=	975	[1+7*0,2317]*½*1,25*22,1²=	800	N/m2
3.1.3	III: bebouwd	[1+7*0,2937]*½*1,25*22,4²=	958			[1+7*0,2937]*½*1,25*20,5²=	803	[1+7*0,2937]*½*1,25*18,6²=	661	N/m2

qp(z) in kN/m2

		zone : omschrijving	
1	gebied 1	0: kustligging	1718,00
2	gebied 1	II: onbebouwd	1160,00
3	gebied 1	III: bebouwd	958,00
4	gebied 2	0: kustligging	1436,00
5	gebied 2	II: onbebouwd	975,00
6	gebied 2	III: bebouwd	803,00
7	gebied 3	II: onbebouwd	800,00
8	gebied 3	III: bebouwd	661,00

resultaten voor qp in verschillende gebeiden en situaties, gebouwhoogte 15m

qp= 800 N/m2 = 0,80 kN/m2

resultaten voor qp gebied 3 onbebouwd, gebouwhoogte 15m

Berekening qp volgens EN1991-1-4 en NB
Waardes en coëfficiënten zijn afkomstig uit de Eurocodes en nationale bijlagen, of worden berekend aan de hand van deze normen. Deze waarden niet wijzigen zonder overleg

1.	opgave coëfficiënten

Fysische waarden				
Aluminium	E mod	70.000	N/mm2	naam eal
	Buigspanning s:	160	N/mm2	naam sigal

1.1	cdir	cdir	1,0	1991 par 4.2 note 2	
1.2	cseason	cseason	1,0	1991 par 4.2 note 3	
1.3	vb,0		vb,0	NB par 4.2 tabel NB1	
		gebied 1	29,5	m/s	
		gebied 2	27,0	m/s	
		gebied 3	24,5	m/s	
1.4	t.b.v. cprob		K	n	NB par 4.2 tabel NB2
		gebied 1	0,2	0,5	
		gebied 2	0,234	0,5	
		gebied 3	0,281	0,5	
1.5.1	referentietijd		15	jaar	
1.5.2	p= 1/referentietijd	1/15=	0,0667		
1.6	orografie factor co(z)	co(z)	1,0	VMRG Gevels en Statica par. 2.1 gebaseerd op vlak terrein (Φ<0,05)	
1.7	turbulentiefactor ki	ki	1,0	1991 par 4.4	
1.8	luchtdichtheid ρ	ρ	1,25	kg/m3	1991 par 4.5 note 2
1.9	ruwheidslengte z0				
		zone : omschrijving	z0	nb tabel 4.1	
1.9.1		0: kustligging	0,005		
1.9.2		II: onbebouwd	0,200		
1.9.3		III: bebouwd	0,500		
1.10	minimum hoogte zmin				
		zone : omschrijving	zmin	nb tabel 4.1	
1.10.1		0: kustligging	1		
1.10.2		II: onbebouwd	4		
1.10.3		III: bebouwd	7		

referentieperiode 15 jaar

2.	Berekeningen (extra) benodigde coëficënten en startwaardes

2.1	vb	vb=vb,0*cdir*cseason=		vb	
2.1.1		gebied 1	29,5*1*1=	29,50	m/s
2.1.2		gebied 2	27*1*1=	27,00	m/s
2.1.3		gebied 3	24,5*1*1=	24,50	m/s

2.2 cprob

$$cprob = \left[\frac{1 - K * ln(-ln(1-p))}{1 - K * ln(-ln(0{,}98))}\right]^n$$ met

K en n volgens 1.4
p volgens 1.5.2

2.2.1	cprob	gebied 1	0,9284
2.2.2		gebied 2	0,9218
2.2.3		gebied 3	0,9140

1-K*ln(-ln(1-p))	1-K*ln(-ln(0,98))
1,534646913	1,780377732
1,625536888	1,913053646
1,751178913	2,096444763

2.3	vbgem	vbgem=vb*cprob	vbgem	
2.3.1		gebied 1	27,40	m/s
2.3.2		gebied 2	24,90	m/s
2.3.3		gebied 3	22,40	m/s

gemiddelde basis windsnelheid (rekenwaarde)

2.4 berekening gemiddelde wind vm(z)

$$vm(z) = cr(z) * co(z) * vbgem$$

met:

co(z) volgens 1.6
vbgem volgens 2.3.1, 2.3.2, 2.3.3

met:

cr(z)=ruwheidsfactor, te berekenen — cr(z) = kr*ln(z/z0)
kr= terreinfactor, te berekenen — kr=0,19*(z0/0,05)^0,07
z0=ruwheidslengte volgens 1.9.1, 1.9.2, 1.9.3
z=hoogte (gebouwhoogte h in de overige berekeningegn)
z mag niet minder zijn dan zmin volgens 1.10.1, 1.10.2, 1.10.3

2.4.1 kr

$$kr = 0{,}19 * \left(\frac{z0}{0{,}05}\right)^{0{,}07}$$

	zone : omschrijving	kr
2.4.1.1	0: kustligging	0,162
2.4.1.2	II: onbebouwd	0,209
2.4.1.3	III: bebouwd	0,223

2.4.2 cr

$$cr(z) = kr * \ln\left(\frac{z}{z0}\right)$$

	z=h=	15,00	m, zie voorblad

	z<zmin?		
	zone : omschrijving	check	z=
2.4.2.1	0: kustligging	FALSE	15,00
2.4.2.2	II: onbebouwd	FALSE	15,00
2.4.2.3	III: bebouwd	FALSE	15,00

	cr(z)	
	zone : omschrijving	cr(z)
2.4.2.4	0: kustligging	1,297
2.4.2.5	II: onbebouwd	0,902
2.4.2.6	III: bebouwd	0,758

vm(z)

	zone : omschrijving	gebied 1		gebied 2		gebied 3		
2.4.2.7	0: kustligging	1,297*1*27,4=	35,5	1,297*1*24,9=	32,3			m/s
2.4.2.8	II: onbebouwd	0,902*1*27,4=	24,7	0,902*1*24,9=	22,5	0,902*1*22,4=	20,2	m/s
2.4.2.9	III: bebouwd	0,758*1*27,4=	20,8	0,758*1*24,9=	18,9	0,758*1*22,4=	17,0	m/s

2.5 bepaling windturbulentie intensiteit Iv(z)

2.5.1 bepaling σv

$$\sigma v = kr * vbgem * ki$$ met

kr volgens 2.4,1,1, 2.4,1.2, 2.4.1.3
ki volgens 1.7

σv

	zone : omschrijving	gebied 1		gebied 2		gebied 3	
2.5.1.1	0: kustligging	0,162*27,4*1=	4,4388	0,162*24,9*1=	4,0338		
2.5.1.2	II: onbebouwd	0,209*27,4*1=	5,7266	0,209*24,9*1=	5,2041	0,209*22,4*1=	4,6816
2.5.1.3	III: bebouwd	0,223*27,4*1=	6,1102	0,223*24,9*1=	5,5527	0,223*22,4*1=	4,9952

2.5.2 Iv(z)

$$Iv(z) = \frac{\sigma v}{vm(z)}$$ met

σv volgens 2.5.1.1, 2.5.1.2, 2.5.1.3
vm(z) =volgens 2.4.2.7, 2.4.2.8, 2.4.2.9

Iv(z)

	zone : omschrijving	gebied 1		gebied 2		gebied 3	
2.5.2.1	0: kustligging	4,4388/35,5=	0,1250	4,0338/32,3=	0,1249		
2.5.2.2	II: onbebouwd	5,7266/24,7=	0,2318	5,2041/22,5=	0,2313	4,6816/20,2=	0,2318
2.5.2.3	III: bebouwd	6,1102/20,8=	0,2938	5,5527/18,9=	0,2938	4,9952/17=	0,2938

3	Berekening qp

3.1 qp

$$qp(z) = [1 + 7 * Iv(z)] * \frac{1}{2} * \rho * vm(z)^2$$ met

Iv(z) volgens 2.5.2.1, 2.5.2.2, 2.5.2.3
ρ volgens 1.8
vm(z) volgens 2.4.2.7,2.4.2.8, 2.4.2.9

	zone : omschrijving	gebied 1		gebied 2		gebied 3		
3.1.1	0: kustligging	[1+7*0,125]*½*1,25*35,5²=	1.477	[1+7*0,1249]*½*1,25*32,3²=	1.222			N/m2
3.1.2	II: onbebouwd	[1+7*0,2318]*½*1,25*24,7²=	1.000	[1+7*0,2313]*½*1,25*22,5²=	829	[1+7*0,2318]*½*1,25*20,2²=	669	N/m2
3.1.3	III: bebouwd	[1+7*0,2938]*½*1,25*20,8²=	827	[1+7*0,2938]*½*1,25*18,9²=	682	[1+7*0,2938]*½*1,25*17²=	552	N/m2

qp(z) in kN/m2

		zone : omschrijving	
1	gebied 1	0: kustligging	1477,00
2	gebied 1	II: onbebouwd	1000,00
3	gebied 1	III: bebouwd	827,00
4	gebied 2	0: kustligging	1222,00
5	gebied 2	II: onbebouwd	829,00
6	gebied 2	III: bebouwd	682,00
7	gebied 3	II: onbebouwd	669,00
8	gebied 3	III: bebouwd	552,00

resultaten voor qp in verschillende gebeiden en situaties, gebouwhoogte 15m

qp= 669 N/m2 = **0,67** kN/m2

resultaten voor qp gebied 3 onbebouwd, gebouwhoogte 15m

APPENDIX F: RESULTS CALCULATIONS

The energy performance of the building is calculated in Uniec2.0 and processed in Excel, see the figures below. In the Excel sheets, the following formulas are used to get more insights into the results. The total energy in the energy calculation is determined by the following formulae:

$$E_{total} = \sum E_{heati} \quad + E_{tapwater} + E_{cooling} + E_{fans} + E_{lightning}$$

The EPG is calculated with the following formulae where 0,05 the weighting factor for CO_2 is in €/kg equivalent.

$$EPG = CO_{2,totaalEPG} * \frac{0{,}05}{BVO}$$

The environmental performance of the building is calculated with the MRPI-MPG tool and is processed in Excel.

The total sustainability performance is calculated as follows.

$$DPG = MPG + EPG$$

$$\% \; CO_2 \; of \; DPG = \frac{CO_{2,totaal} * 0{,}05}{DPG * BVO}$$

All variants are compared to the reference case. Therefore the percentages of improvement are calculated like this:

$$\% \; improvement(DPG_{variant}) = \frac{DPG_{reference} - DPG_{variant}}{DPG_{reference}}$$

$$\% \; improvement(E_{totaal,variant}) = \frac{E_{totaal,reference} - E_{totaal,variant}}{E_{totaal,reference}}$$

Energy performance results

								vacuumgla 5mm			3mm			dubbel vacuum			triple met gorilla		
EPC	0,237	0,246	0,298	0,311	0,356	0,492	0,807	0,254	0,32	0,198	0,311	0,369	0,242	0,202	0,279	0,161	0,237	0,299	0,189
Variant	Triple 16m	Triple 12m	HR++	HR+	HR	Double	Single	vacuumgla	vacuumgla	vacuum m	vacuumgla	vacuumgla	vacuum m	dubbel vac	dubbel zon	met zonwe	gorilla	zonder lam	met zonwering
Heating (excl. backup power supply) (MJ)	157030	171204	226019	245136	309098	443352	842114	158572	117054	117054	222442	174054	174054	101839	68643	68643	157030	113673	113673
backup power supply (MJ)	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	92948	90400	100010	96986	88047	122534	113447	112477	236160	84461	119733	239127	82175	104809	233090	87278	92948	213743	76822
backup power supply (MJ)	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774.185	774.188	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185	774.185
Total energy (MJ)	1.066.513	1.078.139	1.142.564	1.158.657	1.213.680	1.382.421	1.772.096	1.087.584	1.169.749	1.018.050	1.158.710	1.229.716	1.072.764	1.023.183	1.118.268	972.456	1.066.513	1.143.951	1.007.030
CO2 emission (mco2)	17.917	18.629	22.578	23.564	26.936	37.786	64.447	19.208	24.244	14.946	23.567	27.919	18.300	15.261	21.089	12.152	17.917	22.663	14.271
Energy need (kWh/m2)	56,2	57,3	67,2	68,8	74,2	100,8	142,5	62,4	95,1	48,5	72,8	103,3	55,1	52,8	88	43,2	56,2	87,8	45,7
Primary energy use (kWh/m2)	19,2	19,9	24,2	25,2	28,8	39,9	65,5	20,6	25,9	16	25,2	29,9	19,6	16,3	22,5	13	19,2	24,3	15,3
Share of renewable energy (%)	66	66	65	65	65	62	59	64	56	67	63	56	66	66	55	68	66	57	68
% of improvement	0%	-4%	-26%	-31%	-50%	-108%	-241%	-7%	-35%	16%	-31%	-56%	-2%	15%	-18%	32%	0%	-26%	20%

	Insulation value										Insulation value with 20% open facade area									
EPC	0,243	0,239	0,238	0,237	0,236	0,236	0,235	0,235	0,235	0,235	0,213	0,187	0,176	0,169	0,164	0,161	0,16	0,158	0,156	0,155
Variant	RC=1,5	Rc=2,5	RC=3,5	Rc=4,5	RC=5,5	RC=6,5	Rc=7,5	Rc=8,5	Rc=9,5	Rc=10,5	RC=1,5	Rc=2,5	RC=3,5	Rc=4,5	RC=5,5	RC=6,5	Rc=7,5	Rc=8,5	Rc=9,5	Rc=10,5
Heating (excl. backup power supply) (MJ)	165089	160421	158301	157030	156183	155547	155336	154913	154701	154488	166240	134160	119734	111155	105478	101243	99838	97033	95636	94241
backup power supply (MJ)	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	92868	92911	92934	92948	92958	92966	92969	92973	92976	92979	26368	26490	26628	26739	26827	26901	26927	26982	27011	27040
backup power supply (MJ)	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774185	774186	774187	774188	774189	774190	774191	774192	774193	774194	774192	774193	774194	774195	774196	774197	774198	774199	774200	774201
Total energy (MJ)	1074492	1069867	1067770	1066513	1065676	1065048	1064840	1064421	1064212	1064002	1009143	977185	962897	954429	948840	944679	943300	940550	939182	937816
CO2 emission (mco2)	18406	18122	17994	17917	17865	17827	17814	17788	17776	17763	16117	14158	13283	12764	12421	12166	12081	11913	11829	11745
Energy need (kWh/m2)	57,2	56,6	56,4	56,2	56,1	56	56	56	55,9	55,9	37,6	33,6	31,8	30,7	30	29,5	29,3	20	28,8	28,6
Primary energy use (kWh/m2)	19,7	19,4	19,3	19,2	19,1	19,1	19,1	19	19	19	17,2	15,2	14,2	13,7	13,3	13	12,9	12,7	12,7	12,6
Share of renewable energy (%)	66	66	66	66	66	66	66	66	66	66	69	70	70	70	70	71	71	71	71	71
% of improvement	-3%	-1%	0%	0%	0%	0%	1%	1%	1%	1%	10%	21%	26%	29%	31%	32%	32%	33%	34%	35%

	% open/closed facade area						% open/closed facade area with HR++						% open/closed facade area with HR++ without lamella					
EPC	0,26	0,237	0,213	0,19	0,169	0,153	0,333	0,298	0,262	0,224	0,187	0,153	0,404	0,351	0,297	0,242	0,19	0,153
Variant	100% oper	80% open	60% open	40% open	20% open	0% open	100% oper	80% open	60% open	40% open	20% open	0% open	100% oper	80% open	60% open	40% open	20% open	0% open
Heating (excl. backup power supply) (MJ)	170011	157030	142255	126617	111166	96912	252164	226019	197094	165090	131451	96912	189432	174827	156015	135505	114698	96912
backup power supply (MJ)	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	118098	92948	69421	46585	26752	12058	126566	100010	74831	50121	28316	12058	276418	216145	158771	101168	49135	12058
backup power supply (MJ)	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774185	774190	774187	774188	774195	774190	774186	774185	774188	774189	774190	774190	774193	774194	774195	774196	774197	774190
Total energy (MJ)	1104644	1066513	1028211	989737	954453	925505	1195265	1142564	1088460	1031746	976302	925505	1282385	1207507	1131321	1053208	980368	925505
CO2 emission (mco2)	19681	17917	16141	14401	12765	11563	25235	22578	19834	16976	14104	11563	30575	26558	22461	18291	14353	11563
Energy need (kWh/m2)	65,4	56,2	47,3	38,6	30,7	24,6	78,5	67,2	56	44,6	33,8	24,6	116,5	96,4	76,6	56,5	38	24,6
Primary energy use (kWh/m2)	21,1	19,2	17,3	15,4	13,7	12,4	27	24,2	21,2	18,2	15,1	12,4	32,7	28,4	24	19,6	15,4	12,4
Share of renewable energy (%)	65	66	67	69	70	71	63	65	66	68	69	71	55	58	61	64	68	71
% of improvement	-10%	0%	10%	20%	29%	35%	-41%	-26%	-11%	5%	21%	35%	-70%	-48%	-25%	-2%	20%	35%

	% open/closed facade area with HR+					
EPC	0,348	0,311	0,273	0,232	0,191	0,153
Variant	100% oper	HR+	60% open	40% open	20% open	0% open
Heating (excl. backup power supply) (MJ)	274890	245136	212406	175924	137220	96912
backup power supply (MJ)	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	122516	96986	72732	48911	27842	12058
backup power supply (MJ)	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774185	774185	774185	774185	774185	774190
Total energy (MJ)	1213941	1158657	1101673	1041370	981597	925505
CO2 emission (mco2)	26380	23564	20644	17566	14429	11563
Energy need (kWh/m2)	80,2	68,8	57,3	45,6	34,3	24,6
Primary energy use (kWh/m2)	28,2	25,2	22,1	18,8	15,4	12,4
Share of renewable energy (%)	63	65	66	67	69	71
% of improvement	-47%	-31%	-15%	2%	19%	35%

	% open/closed facade area with doubleglazing					
EPC	0,564	0,492	0,414	0,334	0,245	0,153
Variant	100% oper	Dubbel	60% open	40% open	20% open	0% open
Heating (excl. backup power supply) (MJ)	509553	443352	368091	289749	199595	96912
backup power supply (MJ)	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	154590	122534	91602	60818	32975	12058
backup power supply (MJ)	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774185	774185	774185	774185	774185	774190
Total energy (MJ)	1480678	1382421	1276228	1167102	1049105	925505
CO2 emission (mco2)	43647	37786	31342	25272	18566	11563
Energy need (kWh/m2)	117,9	100,8	83,1	63,8	44	24,6
Primary energy use (kWh/m2)	45,7	39,9	33,5	27	19,9	12,4
Share of renewable energy (%)	60	62	64	65	68	71
% of improvement	-138%	-108%	-75%	-41%	-3%	35%

PV panels	N	O	Z	W	Z+O			
EPC	0,197	0,164	0,139	0,164	0,066	0,042	-0,031	-0,104
Variant	144m2 N	144m2 O	144m2 Z	144m2 W	228 Z+O	228 Z	342 (228 Z+	228+228
Heating (excl. backup power supply) (MJ)	157030	157030	157030	157030	157030	157030	157030	157030
backup power supply (MJ)	68703	68703	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	92948	92948	92948	92948	92948	92948	92948	92948
backup power supply (MJ)	39837	39837	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	823300	864687	894784	863701	943899	1015383	1105885	1196387
Total energy (MJ)	1066513	1066513	1066513	1066513	1066513	1066513	1066513	1066513
CO2 emission (mco2)	14906	12370	10525	12430	4978	3134	-2413	-7960
Energy need (kWh/m2)	56,2	56,2	56,2	56,2	56,2	56,2	56,2	56,2
Primary energy use (kWh/m2)	16	13,2	11,3	13,3	5,3	3,4	-1	-3,3
Share of renewable energy (%)	71	75	78	75	89	93	102	107
% of improvement	17%	31%	41%	31%	72%	82%	113%	144%

	Insulation materials	Insulation materials w	Lamella				Aluminium substitute	
EPC	0,237	0,169	0,237	0,237	0,237	0,299	0,237	0,237
Variant			Western re	Nature sto	Fibre ceme	No lamella	Wood	Synthetic
Heating (excl. backup power supply) (MJ)	157030	111166	157030	157030	157030	113673	157030	157030
backup power supply (MJ)	68703	68703	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	92948	26752	92948	92948	92948	213743	92948	92948
backup power supply (MJ)	39837	39837	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774190	774204	774185	774185	774185	774189	774185	774185
Total energy (MJ)	1066513	954453	1066513	1066513	1066513	1143951	1066513	1066513
CO2 emission (mco2)	17917	12765	17917	17917	17917	22663	17917	17917
Energy need (kWh/m2)	56,2	30,7	56,2	56,2	56,2	87,8	56,2	56,2
Primary energy use (kWh/m2)	19,2	13,7	19,2	19,2	19,2	24,3	19,2	19,2
Share of renewable energy (%)	66	70	66	66	66	57	66	66
% of improvement	0%	29%	0%	0%	0%	-26%	0%	0%

	Wooden facade					
EPC	0,441	0,351	0,289	0,226	0,168	0,125
Variant	100% oper	80% open	60% open	40% open	20% open	0% open
Heating (excl. backup power supply) (MJ)	188952	174827	156557	136707	116596	99966
backup power supply (MJ)	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	276809	216145	158410	100479	48311	11439
backup power supply (MJ)	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774194	774195	774196	774197	774198	774199
Total energy (MJ)	1282296	1207507	1131502	1053721	981442	927940
CO2 emission (mco2)	31142	26558	21900	17132	12703	9424
Energy need (kWh/m2)	116,8	96,4	76,3	55,9	37,3	23,9
Primary energy use (kWh/m2)	33,3	28,4	23,4	18,3	13,6	10,1
Share of renewable energy (%)	55	58	61	66	71	76
% of improvement	-86%	-48%	-22%	5%	29%	47%

	Wood with PV on facade			
EPC	0,253	0,156	0,083	0,009
Variant	114 Z	228 Z	228 Z + 114	228 +228
Heating (excl. backup power supply) (MJ)	174827	174827	174827	174827
backup power supply (MJ)	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	216145	216145	216145	216145
backup power supply (MJ)	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0
Humidification (MJ)	0	0	0	0
Fans (MJ)	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896
Induced electricity (MJ)	894784	1015383	1105885	1196387
Total energy (MJ)	1207507	1207507	1207507	1207507
CO2 emission (mco2)	19167	11775	6228	682
Energy need (kWh/m2)	96,4	96,4	96,4	96,4
Primary energy use (kWh/m2)	20,5	12,6	6,7	0,7
Share of renewable energy (%)	67	78	88	99
% of improvement	-7%	34%	65%	96%

	Nature stone facade					
EPC	0,441	0,351	0,289	0,226	0,168	0,125
Variant	100% oper	80% open	60% open	40% open	20% open	0% open
Heating (excl. backup power supply) (MJ)	188952	174827	156557	136707	116596	99966
backup power supply (MJ)	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	276809	216145	158410	100479	48311	11439
backup power supply (MJ)	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774194	774195	774196	774197	774198	774199
Total energy (MJ)	1282296	1207507	1131502	1053721	981442	927940
CO2 emission (mco2)	31142	26558	21900	17132	12703	9424
Energy need (kWh/m2)	116,8	96,4	76,3	55,9	37,3	23,9
Primary energy use (kWh/m2)	33,3	28,4	23,4	18,3	13,6	10,1
Share of renewable energy (%)	55	58	61	66	71	76
% of improvement	-86%	-48%	-22%	5%	29%	47%

	Nature stone with PV on facade			
EPC	0,253	0,156	0,083	0,009
Variant	114 Z	228 Z	228 Z + 11	228 +228
Heating (excl. backup power supply) (MJ)	174827	174827	174827	174827
backup power supply (MJ)	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	216145	216145	216145	216145
backup power supply (MJ)	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0
Humidification (MJ)	0	0	0	0
Fans (MJ)	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896
Induced electricity (MJ)	894784	1015383	1105885	1196387
Total energy (MJ)	1207507	1207507	1207507	1207507
CO2 emission (mco2)	19167	11775	6228	682
Energy need (kWh/m2)	96,4	96,4	96,4	96,4
Primary energy use (kWh/m2)	20,5	12,6	6,7	0,7
Share of renewable energy (%)	67	78	88	99
% of improvement	-7%	34%	65%	96%

	Concrete facade					
EPC	0,441	0,351	0,289	0,226	0,168	0,125
Variant	100% oper	80% open	60% open	40% open	20% open	0% open
Heating (excl. backup power supply) (MJ)	188952	174827	156557	136707	116596	99966
backup power supply (MJ)	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	276809	216145	158410	100479	48311	11439
backup power supply (MJ)	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774194	774195	774196	774197	774198	774199
Total energy (MJ)	1282296	1207507	1131502	1053721	981442	927940
CO2 emission (mco2)	31142	26558	21900	17132	12703	9424
Energy need (kWh/m2)	116,8	96,4	76,3	55,9	37,3	23,9
Primary energy use (kWh/m2)	33,3	28,4	23,4	18,3	13,6	10,1
Share of renewable energy (%)	55	58	61	66	71	76
% of improvement	-86%	-48%	-22%	5%	29%	47%

	Concrete with PV on facade			
EPC	0,253	0,156	0,083	0,009
Variant	114 Z	228 Z	228 Z + 114	228 +228
Heating (excl. backup power supply) (MJ)	174827	174827	174827	174827
backup power supply (MJ)	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	216145	216145	216145	216145
backup power supply (MJ)	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0
Humidification (MJ)	0	0	0	0
Fans (MJ)	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896
Induced electricity (MJ)	894784	1015383	1105885	1196387
Total energy (MJ)	1207507	1207507	1207507	1207507
CO2 emission (mco2)	19167	11775	6228	682
Energy need (kWh/m2)	96,4	96,4	96,4	96,4
Primary energy use (kWh/m2)	20,5	12,6	6,7	0,7
Share of renewable energy (%)	67	78	88	99
% of improvement	-7%	34%	65%	96%

	Sun shades														Realistic transm.	m2 BVO	
EPC	0,19	0,196	0,218	0,189	0,222	0,218	0,19	0,196	0,218	0,189	0,222	0,218	0,172247	0,137182	0,247	0,269	0,195
Variant	1. Auto	1. Hand	1. Perm	1.2 Auto	1.2 Hand	1.2 Perm	1. Auto	2. Hand	2. Perm	2.2 Auto	2.2 Hand	2.2 Perm	2. Optimal	2.1 Optimal		10%	-10%
Heating (excl. backup power supply) (MJ)	157030	157030	212875	113673	113673	212875	157030	157030	212875	113673	113673	212875	157030	113673	171762	153582	159608
backup power supply (MJ)	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	34801	42989	13595	76822	118489	13595	34801	42989	13595	76822	118489	13595	13595	13595	91217	94076	92218
backup power supply (MJ)	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	43144	36047
Summercomfort (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774201	774202	774203	774201	774202	774203	774201	774202	774203	774201	774202	774203	774185	774185	774201	774203	774204
Total energy (MJ)	1008366	1016554	1043005	1007030	1048697	1043005	1008366	1016554	1043005	1007030	1048697	1043005	987160	943803	1079514	1067500	1064571
CO2 emission (mco2)	14353	14855	16476	14271	16825	16476	14353	14855	16476	14271	16825	16476	13054,33	10396,76	18713	21870	13451
Energy need (kWh/m2)	38,3	40,9	39	45,7	58,5	39	38,3	40,9	39	45,7	58,5	39	0	0	57,6	52,4	61,6
Primary energy use (kWh/m2)	15,4	15,9	17,6	15,3	18	17,6	15,4	15,9	17,6	15,3	18	17,6	0	0	20	21,6	15,9
Share of renewable energy (%)	71	70	71	68	64	71	71	70	71	68	64	71	0	0	66	61	72
% of improvement	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	Height facade				Orientation			Service life						Circulair variant			
EPC	0,252	0,267	0,221	0,206	0,202	0,237	0,224	0,237	0,237	0,237	0,237	0,237	0,237	0,237	0,237	0,246	0,237
Variant	10%	20%	-10%	-20%	90 degrees	180 degree	45 degrees	25 years	50 years	75 years	100 years	125 years	150 years	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Heating (excl. backup power supply) (MJ)	170563	183784	143158	129053	129958	156975	147639	157030	157030	157030	157030	157030	157030	157030	157030	171204	157030
backup power supply (MJ)	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703	68703
Hot tapwater (excl. backup power supply) (MJ)	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705	103705
backup power supply (MJ)	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063	1063
Cooling (excl. backup power supply) (MJ)	102189	111549	83852	74913	77436	93016	86691	92948	92948	92948	92948	92948	92948	92948	92948	90400	92948
backup power supply (MJ)	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837	39837
Summercomfort (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Humidification (MJ)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fans (MJ)	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331	192331
Lightning (MJ)	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896	410896
Induced electricity (MJ)	774206	774207	774207	774208	774209	774210	774211	774185	774186	774187	774188	774189	774190	774186	774186	774188	774187
Total energy (MJ)	1089287	1111868	1043545	1020501	1023929	1066526	1050865	1066513	1066513	1066513	1066513	1066513	1066513	1066513	1066513	1078139	1066513
CO2 emission (mco2)	19083	20239	16738	15554	15307	17917	16957	17917	17917	17917	17917	17917	17917	17917	17917	18629	17917
Energy need (kWh/m2)	60,7	65,2	51,7	47,3	48	56,2	53,1	56,2	56,2	56,2	56,2	56,2	56,2	56,2	56,2	57,3	56,2
Primary energy use (kWh/m2)	20,4	21,7	17,9	16,6	16,4	19,2	18,1	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,2	19,9	19,2
Share of renewable energy (%)	65	65	66	67	68	66	66	66	66	66	66	66	66	66	66	66	66
% of improvement	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Environmental performance results

	Unit/ m2 GFO * year	Triple 16 rr BASIS	Triple 12m	HR++	HR+	HR	Double	Single	2x5mm Vacuumgla	Without la	Including s	2x3mm Vacuumgla	Without la	Including s	3x4mm Double vac	Without la	Including s	gorilla gorilla tripl	Without la	Including sun shading
Climate change	kg CO2 eq.	9,75	9,32	9,07	9,06	9,03	9,23	8,38	8,99	8,05	8,7	8,69	7,75	8,34	9,35	8,51	9,17	9,18	8,34	8,93
Schadowcosts of CO2	€	0,4875	0,466	0,4535	0,453	0,4515	0,4615	0,419	0,4495	0,4025	0,435	0,4345	0,3875	0,417	0,4675	0,4255	0,4585	0,459	0,417	0,4465
% shadowcosts CO2 in MPG	%	44%	44%	42%	42%	42%	44%	43%	42%	41%	39%	43%	42%	40%	43%	42%	41%	43%	42%	41%
MPG	€	1,12	1,07	1,08	1,08	1,07	1,06	0,97	1,07	0,99	1,11	1	0,92	1,03	1,08	1,01	1,13	1,06	0,99	1,1
Embodied energy per m2	MJ	130,953	125,178	123,4985	123,3726	122,4024	124,1914	112,8536	122,518	109,1912	121,6144	116,8483	103,5215	114,7686	125,4428	113,674	126,0973	123,1465	111,3777	122,6249
Embodied energy total	MJ	598062,1	571687,7	564017,7	563442,6	559011,5	567182,1	515402,2	559539,6	498676,1	555413,1	533646,1	472782,6	524148,3	572897,2	519149,2	575886,2	562410,1	508662,1	560027,8
Percentage improvement MPG	%	0%	4%	4%	4%	4%	5%	13%	4%	12%	1%	11%	18%	8%	4%	10%	-1%	5%	12%	2%

	Unit/ m2 GFO * year	Insulation value Rc=1,5	Rc=2,5	Rc=3,5	Rc=4,5	Rc=5,5	Rc=6,5	Rc=7,5	Rc=8,5	Rc=9,5	Rc=10,5	Insulation value with 20% open facade area Rc=1,5	Rc=2,5	Rc=3,5	Rc=4,5	Rc=5,5	Rc=6,5	Rc=7,5	Rc=8,5	Rc=9,5	Rc=10,5
Climate change	kg CO2 eq.	9,69	9,71	9,72	9,73	9,75	9,76	9,77	9,79	9,8	9,82	7,49	7,53	7,56	7,59	7,63	7,66	7,69	7,73	7,76	7,8
Schadowcosts of CO2	€	0,4845	0,4855	0,486	0,4865	0,4875	0,488	0,4885	0,4895	0,49	0,491	0,3745	0,3765	0,378	0,3795	0,3815	0,383	0,3845	0,3865	0,388	0,39
% shadowcosts CO2 in MPG	%	43%	43%	43%	43%	44%	44%	44%	44%	44%	43%	43%	43%	43%	43%	43%	43%	43%	43%	44%	43%
MPG	€	1,12	1,12	1,12	1,12	1,12	1,12	1,12	1,12	1,12	1,13	0,88	0,88	0,88	0,88	0,89	0,89	0,89	0,89	0,89	0,9
Embodied energy per m2	MJ	130,1582	130,332	130,512	130,692	130,8658	131,0457	131,2195	131,3995	131,5733	131,7533	100,2602	100,6902	101,1356	101,5809	102,0109	102,4563	102,8862	103,3316	103,7616	104,2069
Embodied energy total	MJ	594432,6	595226,2	596048,2	596870,3	597663,9	598485,9	599279,6	600101,6	600895,2	601717,3	457888,5	459852,3	461886,2	463920,1	465883,8	467917,7	469881,5	471915,4	473879,1	475913
Percentage improvement MPG	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	21%	21%	21%	21%	21%	21%	21%	21%	21%	20%

	Unit/ m2 GFO * year	% open/closed facade area 100% open	80% open	60% open	40% open	20% open	0% open	% open/closed facade area with HR++ 100% open	80% open	60% open	40% open	20% open	0% open	% open/closed facade area with HR++ without lamella 100% open	80% open	60% open	40% open	20% open	0% open
Climate change	kg CO2 eq.	10,3	9,75	8,95	8,27	7,59	6,92	9,45	9,07	8,44	7,93	7,42	6,92	8,41	8,13	7,81	7,51	7,21	6,92
Schadowcosts of CO2	€	0,515	0,4875	0,4475	0,4135	0,3795	0,346	0,4725	0,4535	0,422	0,3965	0,371	0,346	0,4205	0,4065	0,3905	0,3755	0,3605	0,346
% shadowcosts CO2 in MPG	%	43%	44%	43%	43%	43%	43%	41%	42%	42%	42%	42%	43%	40%	41%	41%	41%	42%	43%
MPG	€	1,19	1,12	1,04	0,96	0,88	0,81	1,14	1,08	1,01	0,94	0,88	0,81	1,05	1	0,95	0,91	0,86	0,81
Embodied energy per m2	MJ	138,4447	130,953	120,3345	111,2795	101,5809	93,1856	129,001	123,4985	114,359	107,0412	100,3624	93,1856	114,4213	110,1717	105,9225	101,6733	97,42409	93,1856
Embodied energy total	MJ	632277,1	598062,1	549567,5	508213,6	463920,1	425578,6	589147,7	564017,7	522277,6	488857,3	458354,9	425578,6	522562,1	503154,2	483748,1	464341,9	444935,8	425578,6
Percentage improvement MPG	%	-6%	0%	7%	14%	21%	28%	-2%	4%	10%	16%	21%	28%	6%	11%	15%	19%	23%	28%

	Unit/ m2 GFO * year	% open/closed facade area with HR+ 100% open	80% open	60% open	40% open	20% open	0% open	% open/closed facade area with doubleglazing 100% open	80% open	60% open	40% open	20% open	0% open	PV panels N 114 N	O 114 O	Z 114 Z	W 114 W	Z+O 228 Z+O	228 Z	342 Z + O	456 O + Z
Climate change	kg CO2 eq.	9,44	9,06	8,43	7,92	7,42	6,92	9,64	9,23	8,55	8,01	7,46	6,92	9,97	9,97	9,97	9,97	10,2	10,2	10,4	10,6
Schadowcosts of CO2	€	0,472	0,453	0,4215	0,396	0,371	0,346	0,482	0,4615	0,4275	0,4005	0,373	0,346	0,4985	0,4985	0,4985	0,4985	0,51	0,51	0,52	0,53
% shadowcosts CO2 in MPG	%	41%	42%	42%	44%	43%	43%	43%	44%	43%	45%	43%	43%	43%	43%	43%	43%	43%	43%	43%	42%
MPG	€	1,14	1,08	1	0,9	0,87	0,81	1,12	1,06	0,99	0,89	0,87	0,81	1,15	1,15	1,15	1,15	1,19	1,19	1,22	1,25
Embodied energy per m2	MJ	128,8526	123,3726	114,2798	101,1087	99,71019	93,1856	128,3289	124,1914	114,8934	101,5177	99,90549	93,1856	134,0279	134,0279	134,0279	134,0279	137,4233	137,4233	140,6587	143,894
Embodied energy total	MJ	588469,7	563442,6	521916	461763,6	455376,5	425578,6	586078,2	567182,1	524718,2	463631,2	456268,4	425578,6	612105,3	612105,3	612105,3	612105,3	627612,3	627612,3	642388,1	657163,9
Percentage improvement MPG	%	-2%	4%	11%	20%	22%	28%	0%	5%	12%	21%	22%	28%	-3%	-3%	-3%	-3%	-6%	-6%	-9%	-12%

	Unit/ m2 GFO * year	Insulation materials steenwol	vlaswol	schapenwc	EPS plaat (:	houtvezel	glaswol	cellenbeto	metisse (ka	schuimisol.	cellulair glas	Isolatiemateriaal met 20% open delen Rockwool	Flax wool	Sheep woo	EPS panel	Woodfibre	Glass ficre	Aerated co	Metisse (cc	Cellular ins	Cellular gla
Climate change	kg CO2 eq.	9,7	9,69	10,7	9,76	9,68	9,68	9,82	9,69	9,73	9,73	7,5	7,5	9,93	7,66	7,45	7,47	7,8	7,48	7,58	7,91
Schadowcosts of CO2	€	0,485	0,4845	0,535	0,488	0,484	0,484	0,491	0,4845	0,4865	0,4865	0,375	0,375	0,4965	0,383	0,3725	0,3735	0,39	0,374	0,379	0,3955
% shadowcosts CO2 in MPG	%	43%	43%	42%	43%	44%	43%	44%	43%	43%	43%	43%	43%	38%	43%	41%	43%	43%	43%	43%	43%
MPG	€	1,12	1,12	1,28	1,13	1,11	1,12	1,12	1,12	1,12	1,13	0,88	0,88	1,29	0,9	0,9	0,87	0,9	0,88	0,88	0,91
Embodied energy per m2	MJ	130,2983	130,7011	135,383	131,1251	130,0896	130,3264	131,5101	130,664	130,0355	132,8904	100,6077	101,6044	113,1898	102,6607	108,2291	100,6897	103,6191	101,5244	99,95287	107,0165
Embodied energy total	MJ	595072,2	596911,7	618293,9	598848,5	594119,2	595200,8	600606,6	596742,6	593872	606910,7	459475,5	464027,1	516937,8	468851,2	494282,5	459850,1	473228,2	463661,9	456484,7	488744,6
Percentage improvement MPG	%	0%	0%	-14%	-1%	1%	0%	0%	0%	0%	-1%	21%	21%	-15%	20%	20%	22%	20%	21%	21%	19%

	Unit/ m2 GFO * year	Lamella Western rc	Nature sto	Fibre ceme	No lamella	Aluminium substitute Wood	Synthetic	Wooden facade 100% open	80% open	60% open	40% open	20% open	0% open	Wood with PV on facade 114 Z	228 Z	228Z+114C	228Z+228C
Climate change	kg CO2 eq.	9,44	9,46	8,87	8,81	9,57	9,69	7,76	7,5	7,24	6,98	6,72	6,46	7,72	7,94	8,16	8,38
Schadowcosts of CO2	€	0,472	0,473	0,4435	0,4405	0,4785	0,4845	0,388	0,375	0,362	0,349	0,336	0,323	0,386	0,397	0,408	0,419
% shadowcosts CO2 in MPG	%	42%	43%	42%	42%	41%	44%	41%	42%	42%	43%	43%	44%	42%	41%	41%	41%
MPG	€	1,13	1,09	1,05	1,04	1,16	1,11	0,94	0,9	0,86	0,82	0,78	0,74	0,93	0,96	0,99	1,02
Embodied energy per m2	MJ	160,5201	126,1166	119,4351	117,6259	171,2907	129,4045	110,58	106,6659	102,7539	98,84196	94,93002	91,02538	109,7411	112,8164	115,8916	118,9668
Embodied energy total	MJ	733095,5	575974,6	545460,3	537197,3	782284,8	590990,4	505019,1	487143,1	469277,1	451411,2	433545,4	415712,9	501187,7	515232,3	529276,9	543321,4
Percentage improvement MPG	%	-1%	3%	6%	7%	-4%	1%	16%	20%	23%	27%	30%	34%	17%	14%	12%	9%

		Nature stone facade						Nature stone with PV on facade				Concrete facade					
		100% open	80% open	60% open	40% open	20% open	0% open	114 Z	228 Z	228Z+114C	228Z+228O	100% open	80% open	60% open	40% open	20% open	0% open
	Unit/ m2 GFO * year																
Climate change	kg CO2 eq.	7,85	7,84	7,84	7,83	7,83	7,82	8,07	8,29	8,51	8,73	8,05	7,92	7,8	7,68	7,55	7,43
Schadowcosts of CO2	€	0,3925	0,392	0,392	0,3915	0,3915	0,391	0,4035	0,4145	0,4255	0,4365	0,4025	0,396	0,39	0,384	0,3775	0,3715
% shadowcosts CO2 in MPG	%	41%	42%	43%	43%	44%	45%	42%	41%	41%	41%	40%	41%	42%	43%	44%	45%
MPG	€	0,95	0,93	0,92	0,91	0,89	0,87	0,97	1	1,03	1,07	1,01	0,97	0,93	0,9	0,86	0,83
Embodied energy per m2	MJ	113,0034	111,0805	111,5642	111,5306	112,5072	112,9893	114,1557	114,1557	117,2309	125,4487	112,7217	109,8676	107,0192	104,1707	101,3223	98,48203
Embodied energy total	MJ	516086,6	507304,6	509513,5	509360,2	513820,5	516022	521349,1	521349,1	535393,7	572924	514799,8	501765,3	488756,6	475747,8	462739	449767,4
Percentage improvement MPG	%	15%	17%	18%	19%	21%	22%	13%	11%	8%	4%	10%	13%	17%	20%	23%	26%

		Concrete with PV on facade					Sun shading													
		114 Z	228 Z	228Z+114C	228Z+228C	Reference	1. Auto	1. Hand	1. Perm	1.2 Auto	1.2 Hand	1.2 Perm	1. Auto	2. Hand	2. Perm	2.2 Auto	2.2 Hand	2.2 Perm	2. Optimal	2.1 Optima
	Unit/ m2 GFO * year																			
Climate change	kg CO2 eq.	8,15	8,34	8,51	8,75		10,5	10,5	10,5	9,65	9,65	9,65	10,3	10,3	10,3	9,4	9,4	9,4	10,3	9,4
Schadowcosts of CO2	€	0,4075	0,417	0,4255	0,4375		0,525	0,525	0,525	0,4825	0,4825	0,4825	0,515	0,515	0,515	0,47	0,47	0,47	0,515	0,47
% shadowcosts CO2 in MPG	%	41%	40%	40%	40%		36%	36%	36%	35%	35%	35%	42%	42%	42%	41%	41%	41%	42%	41%
MPG	€	1	1,03	1,06	1,09		1,45	1,45	1,45	1,37	1,37	1,37	1,23	1,23	1,23	1,15	1,15	1,15	1,23	1,15
Embodied energy per m2	MJ	112,9428	116,0181	119,0933	122,1685		144,5974	144,5974	144,5974	131,2706	131,2706	131,2706	142,1998	142,1998	142,1998	128,8783	128,8783	128,8783	142,1998	128,8783
Embodied energy total	MJ	515809,9	529854,5	543899,1	557943,7		660376,2	660376,2	660376,2	599512,8	599512,8	599512,8	649426,4	649426,4	649426,4	588587,1	588587,1	588587,1	649426,4	588587,1
Percentage improvement MPG	%	11%	8%	5%	3%		-29%	-29%	-29%	-22%	-22%	-22%	-10%	-10%	-10%	-3%	-3%	-3%	-10%	-3%

		Transmission realistic	m2 BVO		Height facade				Orientation			Service life					
		0	10%	-10%	10%	20%	-10%	-20%	90 graden	180 grader	45 graden	25 years	50 years	75 years	100 years	125 years	150 years
	Unit/ m2 GFO * year																
Climate change	kg CO2 eq.	9,75	8,87	10,8	9,92	10,2	9,32	9,02	9,75	9,75	9,75	15,5	9,75	8,02	7,53	7,24	7,05
Schadowcosts of CO2	€	0,4875	0,4435	0,54	0,496	0,51	0,466	0,451	0,4875	0,4875	0,4875	0,775	0,4875	0,401	0,3765	0,362	0,3525
% shadowcosts CO2 in MPG	%	44%	43%	43%	44%	43%	43%	43%	44%	44%	44%	45%	44%	43%	42%	42%	42%
MPG	€	1,12	1,02	1,25	1,14	1,18	1,08	1,04	1,12	1,12	1,12	1,73	1,12	0,94	0,89	0,86	0,84
Embodied energy per m2	MJ	130,953	119,0408	145,5136	133,4781	137,5615	125,3112	121,2278	130,953	130,953	130,953	200,5776	130,953	110,7755	103,8428	99,72845	96,94782
Embodied energy total	MJ	598062,1	543659,1	664560,4	609594,3	628243,3	572296,2	553647,2	598062,1	598062,1	598062,1	916038,1	598062,1	505911,7	474250	455459,8	442760,7
Percentage improvement MPG	%	0%	9%	-12%	-2%	-5%	4%	7%	0%	0%	0%	-54%	0%	16%	21%	23%	25%

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Unit/ m2 GFO * year				
Climate change	kg CO2 eq.	9,75	19,3	9,57	9,33
Schadowcosts of CO2	€	0,4875	0,965	0,47	0,46
% shadowcosts CO2 in MPG	%	44%	45%	44%	44%
MPG	€	1,12	2,15	1,09	1,07
Embodied energy per m2	MJ	130,953	249,4491	128,56	125,34
Embodied energy total	MJ	598062,1	1139234	587152,5	572442,8
Percentage improvement MPG	%	0%	-92%	-90%	5%

Sustainability performance results

									2x5mm			2x3mm			3x4mm					
	BASIS	Triple 16 mm	Triple 12mm	HR++	HR+	HR	Double	Single	Vacuumglazing	Without lam	Including sun	Vacuumglazing	Without lam	Including sun sl	Double vacuum	Without lam	Including sun	gorilla triple	Without lam	Including sun shading
Total CO2 EPG	17917,00	17917,00	18629,00	22578,00	23564,00	26936,00	37786,00	64447,00	19208,00	24244,00	14946,00	23567,00	27919,00	18300,00	15261,00	21089,00	12152,00	17917,00	22663,00	14271,00
Total CO2 MPG	44528,25	44528,25	42564,44	41422,69	41377,02	41240,01	42153,41	38271,46	41057,33	36764,35	39732,90	39687,23	35394,25	38088,78	42701,45	38865,17	41879,39	41925,06	38088,78	40783,31
Total CO2	62445,25	62445,25	61193,44	64000,69	64941,02	68176,01	79939,41	102718,46	60265,33	61008,35	54678,90	63254,23	63313,25	56388,78	57962,45	59954,17	54031,39	59842,06	60751,78	55054,31
EPG	0,20	0,20	0,20	0,25	0,26	0,29	0,41	0,71	0,21	0,27	0,16	0,26	0,31	0,20	0,17	0,23	0,13	0,20	0,25	0,16
MPG	1,12	1,12	1,07	1,08	1,08	1,07	1,06	0,97	1,07	0,99	1,11	1,00	0,92	1,03	1,08	1,01	1,13	1,06	0,99	1,10
DPG	1,32	1,32	1,27	1,33	1,34	1,36	1,47	1,68	1,28	1,26	1,27	1,26	1,23	1,23	1,25	1,24	1,26	1,26	1,24	1,26
CO2 part of DPG	0,68	0,68	0,67	0,70	0,71	0,75	0,88	1,12	0,66	0,67	0,60	0,69	0,69	0,62	0,63	0,66	0,59	0,66	0,67	0,60
% co2 van DPG	0,52	0,52	0,53	0,53	0,53	0,55	0,59	0,67	0,52	0,53	0,47	0,55	0,57	0,50	0,51	0,53	0,47	0,52	0,54	0,48
Energy demand	1066513,00	1066513,00	1078139,00	1142564,00	1158657,00	1213680,00	1382421,00	1772096,00	1087584,00	1169749,00	1018050,00	1158710,00	1229716,00	1072764,00	1023183,00	1118268,00	972456,00	1066513,00	1143951,00	1007030,00
Energy demand - induced energy	292328,00	292328,00	303951,00	368379,00	384472,00	439495,00	608236,00	997911,00	313399,00	395564,00	243865,00	384525,00	455531,00	298579,00	248998,00	344083,00	198271,00	292328,00	369766,00	232845,00
Embodied energy	598062,15	598062,15	571687,72	564017,66	563442,62	559011,54	567182,11	515402,17	559539,56	498676,08	555413,09	533646,13	472782,64	524148,33	572897,19	519149,17	575886,18	562410,08	508662,06	560027,75
Total energy	1664575,15	1664575,15	1649826,72	1706581,66	1722099,62	1772691,54	1949603,11	2287498,17	1647123,56	1668425,08	1573463,09	1692356,13	1702498,64	1596912,33	1596080,19	1637417,17	1548342,18	1628923,08	1652613,06	1567057,75
Total energy - induced energy	890390,15	890390,15	875638,72	932396,66	947914,62	998506,54	1175418,11	1513313,17	872938,56	894240,08	799278,09	918171,13	928313,64	822727,33	821895,19	863232,17	774157,18	854738,08	878428,06	792872,75
% improvement EPG	0%	0%	-4%	-26%	-31%	-50%	-108%	-241%	-7%	-35%	16%	-31%	-56%	-2%	15%	-18%	32%	0%	-26%	20%
% improvement MPG	0%	0%	4%	4%	4%	4%	5%	13%	4%	12%	1%	11%	18%	8%	4%	10%	-1%	5%	12%	2%
% improvement DPG	0%	0%	3%	-0,5%	-1,4%	-3%	-12%	-27%	3%	5%	4%	5%	7%	7%	6%	6%	4%	5%	6%	5%
% improvement energy demand	0%	0%	-1%	-7%	-9%	-14%	-30%	-66%	-2%	-10%	5%	-9%	-15%	-1%	4%	-5%	9%	0%	-7%	6%
% improvement embodied energy	0%	0%	4%	6%	6%	7%	5%	14%	6%	17%	7%	11%	21%	12%	4%	13%	4%	6%	15%	6%
% improvement total energy	0%	0%	1%	-3%	-3%	-6%	-17%	-37%	1%	0%	5%	-2%	-2%	4%	4%	2%	7%	2%	1%	6%

	Insulation value										Insulation value with 20% open parts in facade									
	Rc=1,5	Rc=2,5	Rc=3,5	Rc=4,5	Rc=5,5	Rc=6,5	Rc=7,5	Rc=8,5	Rc=9,5	Rc=10,5	Rc=1,5	Rc=2,5	Rc=3,5	Rc=4,5	Rc=5,5	Rc=6,5	Rc=7,5	Rc=8,5	Rc=9,5	Rc=10,5
Total CO2 EPG	18406,00	18122,00	17994,00	17917,00	17865,00	17827,00	17814,00	17788,00	17776,00	17763,00	16117,00	14158,00	13283,00	12764,00	12421,00	12166,00	12081,00	11913,00	11829,00	11745,00
Total CO2 MPG	44254,23	44345,57	44391,24	44436,91	44528,25	44573,92	44619,59	44710,93	44756,60	44847,94	34206,83	34389,51	34526,52	34663,53	34846,21	34983,22	35120,23	35302,91	35439,92	35622,60
Total CO2	62660,23	62467,57	62385,24	62353,91	62393,25	62400,92	62433,59	62498,93	62532,60	62610,94	50323,83	48547,51	47809,52	47427,53	47267,21	47149,22	47201,23	47215,91	47268,92	47367,60
EPG	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,19	0,19	0,19	0,18	0,16	0,15	0,14	0,14	0,13	0,13	0,13	0,13	0,13
MPG	1,12	1,12	1,12	1,12	1,12	1,12	1,12	1,12	1,12	1,13	0,88	0,88	0,88	0,88	0,89	0,89	0,89	0,89	0,89	0,90
DPG	1,32	1,32	1,32	1,32	1,32	1,32	1,32	1,31	1,31	1,32	1,06	1,04	1,03	1,02	1,03	1,02	1,02	1,02	1,02	1,03
CO2 part of DPG	0,69	0,68	0,68	0,68	0,68	0,68	0,68	0,68	0,68	0,69	0,55	0,53	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52
% co2 van DPG	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,51	0,51	0,51	0,50	0,50	0,51	0,51	0,51	0,50
Energy demand	1074492,00	1069867,00	1067770,00	1066513,00	1065676,00	1065048,00	1064840,00	1064421,00	1064212,00	1064002,00	1009143,00	977185,00	962897,00	954429,00	948840,00	944679,00	943300,00	940550,00	939182,00	937816,00
Energy demand - induced energy	300307,00	295681,00	293583,00	292328,00	291487,00	290858,00	290649,00	290229,00	290019,00	289808,00	234951,00	202992,00	188703,00	180234,00	174644,00	170482,00	169102,00	166351,00	164982,00	163615,00
Embodied energy	594432,58	595226,24	596048,24	596870,25	597663,91	598485,92	599279,58	600101,59	600895,25	601717,26	457888,51	459852,27	461886,17	463920,06	465883,82	467917,71	469881,47	471915,37	473879,13	475913,02
Total energy	1668924,58	1665093,24	1663818,24	1663383,25	1663339,91	1663533,92	1664119,58	1664522,59	1665107,25	1665719,26	1467031,51	1437037,27	1424783,17	1418349,06	1414723,82	1412596,71	1413181,47	1412465,37	1413061,13	1413729,02
Total energy - induced energy	894739,58	890907,24	889631,24	889198,25	889150,91	889343,92	889928,58	890330,59	890914,25	891525,26	692839,51	662844,27	650589,17	644154,06	640527,82	638399,71	638983,47	638266,37	638861,13	639528,02
% improvement EPG	-3%	-1%	0%	0%	0%	0%	1%	1%	1%	1%	10%	21%	26%	29%	31%	32%	32%	33%	34%	35%
% improvement MPG	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	21%	21%	21%	21%	21%	21%	21%	21%	21%	20%
% improvement DPG	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	22%	22%	23%	22%	22%	23%	23%	23%	22%
% improvement energy demand	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	8%	10%	11%	11%	11%	12%	12%	12%	12%
% improvement embodied energy	1%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	23%	23%	23%	22%	22%	22%	21%	21%	21%	20%
% improvement total energy	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	12%	14%	14%	15%	15%	15%	15%	15%	15%	15%

	% open/closed facade area						% open/closed facade area with HR++						% open/closed facade area with HR++ without lamella					
	100% open	80% open	60% open	40% open	20% open	0% open	100% open	80% open	60% open	40% open	20% open	0% open	100% open	80% open	60% open	40% open	20% open	0% open
Total CO2 EPG	19681,00	17917,00	16141,00	14401,00	12765,00	11563,00	25235,00	22578,00	19834,00	16976,00	14104,00	11563,00	30575,00	26558,00	22461,00	18291,00	14353,00	11563,00
Total CO2 MPG	47040,10	44528,25	40874,65	37769,09	34663,53	31603,64	43158,15	41422,69	38545,48	36216,31	33887,14	31603,64	38408,47	37129,71	35668,27	34298,17	32928,07	31603,64
Total CO2	66721,10	62445,25	57015,65	52170,09	47428,53	43166,64	68393,15	64000,69	58379,48	53192,31	47991,14	43166,64	68983,47	63687,71	58129,27	52589,17	47281,07	43166,64
EPG	0,22	0,20	0,18	0,16	0,14	0,13	0,28	0,25	0,22	0,19	0,15	0,13	0,33	0,29	0,25	0,20	0,16	0,13
MPG	1,19	1,12	1,04	0,96	0,88	0,81	1,14	1,08	1,01	0,94	0,88	0,81	1,05	1,00	0,95	0,91	0,86	0,81
DPG	1,41	1,32	1,22	1,12	1,02	0,94	1,42	1,33	1,23	1,13	1,03	0,94	1,38	1,29	1,20	1,11	1,02	0,94
CO2 part of DPG	0,73	0,68	0,62	0,57	0,52	0,47	0,75	0,70	0,64	0,58	0,53	0,47	0,76	0,70	0,64	0,58	0,52	0,47
% co2 van DPG	0,52	0,52	0,51	0,51	0,51	0,50	0,53	0,53	0,52	0,52	0,51	0,50	0,55	0,54	0,53	0,52	0,51	0,50
Energy demand	1104644,00	1066513,00	1028211,00	989737,00	954453,00	925505,00	1195265,00	1142564,00	1088460,00	1031746,00	976302,00	925505,00	1282385,00	1207507,00	1131321,00	1053208,00	980368,00	925505,00
Energy demand - induced energy	330459,00	292323,00	254024,00	215549,00	180258,00	151315,00	421079,00	368379,00	314272,00	257557,00	202112,00	151315,00	508192,00	433313,00	357126,00	279012,00	206171,00	151315,00
Embodied energy	632277,12	598062,15	549567,51	508213,62	463920,06	425578,64	589147,67	564017,66	522277,57	488857,26	458354,93	425578,64	522562,13	503154,18	483748,07	464341,95	444935,83	425578,64
Total energy	1736921,12	1664575,15	1577778,51	1497950,62	1418373,06	1351083,64	1784412,67	1706581,66	1610737,57	1520603,26	1434656,93	1351083,64	1804947,13	1710661,18	1615069,07	1517549,95	1425303,83	1351083,64
Total energy - induced energy	962736,12	890385,15	803591,51	723762,62	644178,06	576893,64	1010226,67	932396,66	836549,57	746414,26	660466,93	576893,64	1030754,13	936467,18	840874,07	743353,95	651106,83	576893,64
% improvement EPG	-10%	0%	10%	20%	29%	35%	-41%	-26%	-11%	5%	21%	35%	-70%	-48%	-25%	-2%	20%	35%
% improvement MPG	-6%	0%	7%	14%	21%	28%	-2%	4%	10%	16%	21%	28%	6%	11%	15%	19%	23%	28%
% improvement DPG	-6%	0%	8%	15%	23%	29%	-7%	-1%	7%	15%	22%	29%	-5%	2%	9%	16%	23%	29%
% improvement energy demand	-4%	0%	4%	7%	11%	13%	-12%	-7%	-2%	3%	8%	13%	-20%	-13%	-6%	1%	8%	13%
% improvement embodied energy	-6%	0%	8%	15%	22%	29%	1%	6%	13%	18%	23%	29%	13%	16%	19%	22%	26%	29%
% improvement total energy	-4%	0%	5%	10%	15%	19%	-7%	-3%	3%	9%	14%	19%	-8%	-3%	3%	9%	14%	19%

	% open/closed facade area with HR+						% open/closed facade area with doubleglazing						PV panels N	O	Z	W	Z+O	Z	Z+O	Z+O
	100% open	80% open	60% open	40% open	20% open	0% open	100% open	80% open	60% open	40% open	20% open	0% open	114 N	114 O	114 Z	114 W	228 Z+O	228 Z	342 Z+O	456 O+Z
Total CO2 EPG	26380,00	23564,00	20644,00	17566,00	14429,00	11563,00	43647,00	37786,00	31342,00	25272,00	18566,00	11563,00	14906,00	12370,00	10525,00	12430,00	4978,00	3134,00	-2413,00	-7960,00
Total CO2 MPG	43112,48	41377,02	38499,81	36170,64	33887,14	31603,64	44025,88	42153,41	39047,85	36581,67	34069,82	31603,64	45532,99	45532,99	45532,99	45532,99	46583,40	46583,40	47496,80	48410,20
Total CO2	69492,48	64941,02	59143,81	53736,64	48316,14	43166,64	87672,88	79939,41	70389,85	61853,67	52635,82	43166,64	60438,99	57902,99	56057,99	57962,99	51561,40	49717,40	45083,80	40450,20
EPG	0,29	0,26	0,23	0,19	0,16	0,13	0,48	0,41	0,34	0,28	0,20	0,13	0,16	0,14	0,12	0,14	0,05	0,03	-0,03	-0,09
MPG	1,14	1,08	1,00	0,90	0,87	0,81	1,12	1,06	0,99	0,89	0,87	0,81	1,15	1,15	1,15	1,15	1,19	1,19	1,22	1,25
DPG	1,43	1,34	1,23	1,09	1,03	0,94	1,60	1,47	1,33	1,17	1,07	0,94	1,31	1,29	1,27	1,29	1,24	1,22	1,19	1,16
CO2 part of DPG	0,76	0,71	0,65	0,59	0,53	0,47	0,96	0,88	0,77	0,68	0,58	0,47	0,66	0,63	0,61	0,63	0,56	0,54	0,49	0,44
% co2 van DPG	0,53	0,53	0,53	0,54	0,51	0,50	0,60	0,59	0,58	0,58	0,54	0,50	0,50	0,49	0,49	0,49	0,45	0,44	0,41	0,38
Energy demand	1213941,00	1158657,00	1101673,00	1041370,00	981597,00	925505,00	1480678,00	1382421,00	1276228,00	1167102,00	1049105,00	925505,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00
Energy demand - induced energy	439756,00	384472,00	327488,00	267185,00	207412,00	151315,00	706493,00	608236,00	502043,00	392917,00	274920,00	151315,00	243213,00	201826,00	171729,00	202812,00	122614,00	51130,00	-39372,00	-129874,00
Embodied energy	588469,73	563442,62	521916,04	461763,59	455376,46	425578,64	586078,22	567182,11	524718,15	463631,18	456268,35	425578,64	612105,33	612105,33	612105,33	612105,33	627612,33	627612,33	642388,13	657163,92
Total energy	1802410,73	1722099,62	1623589,04	1503133,59	1436973,46	1351083,64	2066756,22	1949603,11	1800946,15	1630733,18	1505373,35	1351083,64	1678618,33	1678618,33	1678618,33	1678618,33	1694125,33	1694125,33	1708901,13	1723676,92
Total energy - induced energy	1028225,73	947914,62	849404,04	728948,59	662788,46	576893,64	1292571,22	1175418,11	1026761,15	856548,18	731188,35	576893,64	855318,33	813931,33	783834,33	814917,33	750226,33	678742,33	603016,13	527289,92
% improvement EPG	-47%	-31%	-15%	2%	19%	35%	-138%	-108%	-75%	-41%	-3%	35%	17%	31%	41%	31%	72%	82%	113%	144%
% improvement MPG	-2%	4%	11%	20%	22%	28%	0%	5%	12%	21%	22%	28%	-3%	-3%	-3%	-3%	-6%	-6%	-9%	-12%
% improvement DPG	-8%	-1%	7%	17%	22%	29%	-21%	-12%	-1%	12%	19%	29%	1%	3%	4%	3%	6%	7%	10%	12%
% improvement energy demand	-14%	-9%	-3%	2%	8%	13%	-39%	-30%	-20%	-9%	2%	13%	0%	0%	0%	0%	0%	0%	0%	0%
% improvement embodied energy	2%	6%	13%	23%	24%	29%	2%	5%	12%	22%	24%	29%	-2%	-2%	-2%	-2%	-5%	-5%	-7%	-10%
% improvement total energy	-8%	-3%	2%	10%	14%	19%	-24%	-17%	-8%	2%	10%	19%	-1%	-1%	-1%	-1%	-2%	-2%	-3%	-4%

	Insulation materials										Insulation materials with 20% open									
	steenwol	vlaswol	schapenwol	EPS plaat (stybenex 3	houtvezel	glaswol	cellenbeton	metisse (katoen	schuimisolatie biopo	cellulair glas	Rockwool	Flax wool	Sheep wool	EPS panel	Woodfibre	Glass ficre	Aerated concrete	Metisse (cotton)	Cellular insulation bi	Cellular glass
Total CO2 EPG	17917,00	17917,00	17917,00	17917,00	17917,00	17917,00	17917,00	17917,00	17917,00	17917,00	12765,00	12765,00	12765,00	12765,00	12765,00	12765,00	12765,00	12765,00	12765,00	12765,00
Total CO2 MPG	44299,90	44254,23	48866,90	44573,92	44208,56	44208,56	44847,94	44254,23	44436,91	44436,91	34252,50	34252,50	45350,31	34983,22	34024,15	34115,49	35622,60	34161,16	34617,86	36124,97
Total CO2	62216,90	62171,23	66783,90	62490,92	62125,56	62125,56	62764,94	62171,23	62353,91	62353,91	47017,50	47017,50	58115,31	47748,22	46789,15	46880,49	48387,60	46926,16	47382,86	48889,97
EPG	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14
MPG	1,12	1,12	1,28	1,13	1,11	1,12	1,12	1,12	1,12	1,13	0,88	0,88	1,29	0,90	0,90	0,87	0,90	0,88	0,88	0,91
DPG	1,32	1,32	1,48	1,33	1,31	1,32	1,32	1,32	1,32	1,33	1,02	1,02	1,43	1,04	1,04	1,01	1,04	1,02	1,02	1,05
CO2 part of DPG	0,68	0,68	0,73	0,68	0,68	0,68	0,69	0,68	0,68	0,68	0,51	0,51	0,64	0,52	0,51	0,51	0,53	0,51	0,52	0,54
% co2 van DPG	0,52	0,52	0,50	0,52	0,52	0,52	0,52	0,52	0,52	0,51	0,50	0,50	0,45	0,50	0,49	0,51	0,51	0,50	0,51	0,51
Energy demand	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	954453,00	954453,00	954453,00	954453,00	954453,00	954453,00	954453,00	954453,00	954453,00	954453,00
Energy demand - induced energy	292323,00	292322,00	292321,00	292320,00	292319,00	292318,00	292317,00	292316,00	292315,00	292314,00	180258,00	180257,00	180256,00	180255,00	180254,00	180253,00	180252,00	180251,00	180250,00	180249,00
Embodied energy	595072,17	596911,71	618293,94	598848,45	594119,17	595200,82	600606,56	596742,60	593871,97	606910,66	459475,55	464027,13	516937,83	468851,21	494282,47	459850,08	473228,25	463661,85	456484,74	488744,57
Total energy	1661585,17	1663424,71	1684806,94	1665361,45	1660632,17	1661713,82	1667119,56	1663255,60	1660384,97	1673423,66	1413928,55	1418480,13	1471390,83	1423304,21	1448735,47	1414303,08	1427681,25	1418114,85	1410937,74	1443197,57
Total energy - induced energy	887395,17	889233,71	910614,94	891168,45	886438,17	887518,82	892923,56	889058,60	886186,97	899224,66	639733,55	644284,13	697193,83	649106,21	674536,47	640103,08	653480,25	643912,85	636734,74	668993,57
% improvement EPG	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	29%	29%	29%	29%	29%	29%	29%	29%	29%	29%
% improvement MPG	0%	0%	-14%	-1%	1%	0%	0%	0%	0%	-1%	21%	21%	-15%	20%	20%	22%	20%	21%	21%	19%
% improvement DPG	0%	0%	-12%	0%	1%	0%	0%	0%	0%	0%	23%	23%	-8%	21%	21%	24%	21%	23%	23%	20%
% improvement energy demand	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	11%	11%	11%	11%	11%	11%	11%	11%	11%
% improvement embodied energy	0%	0%	-3%	0%	1%	0%	0%	0%	1%	-1%	23%	22%	14%	22%	17%	23%	21%	22%	24%	18%
% improvement total energy	0%	0%	-1%	0%	0%	0%	0%	0%	0%	-1%	15%	15%	12%	14%	13%	15%	14%	15%	15%	13%

	Lamella				Aluminium substitute		Wooden facade						Wood with PV on facade			
	Western red cedar	Nature stone	Fibre cement panel	No lamella	Wood	Synthetic	100% open	80% open	60% open	40% open	20% open	0% open	114 Z	228 Z	228Z+114O	228Z+228O
Total CO2 EPG	17917,00	17917,00	17917,00	22663,00	17917,00	17917,00	31142,00	26558,00	21900,00	17132,00	12703,00	9424,00	19167,00	11775,00	6228,00	682,00
Total CO2 MPG	43112,48	43203,82	40509,29	40235,27	43706,19	44254,23	35439,92	34252,50	33065,08	31877,66	30690,24	29502,82	35257,24	36261,98	37266,72	38271,46
Total CO2	61029,48	61120,82	58426,29	62898,27	61623,19	62171,23	66581,92	60810,50	54965,08	49009,66	43393,24	38926,82	54424,24	48036,98	43494,72	38953,46
EPG	0,20	0,20	0,20	0,25	0,20	0,20	0,34	0,29	0,24	0,19	0,14	0,10	0,21	0,13	0,07	0,01
MPG	1,13	1,09	1,05	1,04	1,16	1,11	0,94	0,90	0,86	0,82	0,78	0,74	0,93	0,96	0,99	1,02
DPG	1,33	1,29	1,25	1,29	1,36	1,31	1,28	1,19	1,10	1,01	0,92	0,84	1,14	1,09	1,06	1,03
EPG	0,20	0,20	0,20	0,25	0,20	0,20	0,34	0,29	0,24	0,19	0,14	0,10	0,21	0,13	0,07	0,01
CO2 part of DPG	0,67	0,67	0,64	0,69	0,67	0,68	0,73	0,67	0,60	0,54	0,48	0,43	0,60	0,53	0,48	0,43
% co2 van DPG	0,50	0,52	0,51	0,53	0,50	0,52	0,57	0,56	0,55	0,53	0,52	0,51	0,52	0,48	0,45	0,42
Energy demand	1066513,00	1066513,00	1066513,00	1143951,00	1066513,00	1066513,00	1282296,00	1207507,00	1131502,00	1053721,00	981442,00	927940,00	1207507,00	1207507,00	1207507,00	1207507,00
Energy demand - induced energy	292328,00	292328,00	292328,00	369762,00	292328,00	292328,00	508102,00	433312,00	357306,00	279524,00	207244,00	153741,00	312723,00	192124,00	101622,00	11120,00
Embodied energy	733095,52	575974,58	545460,32	537197,26	782284,75	590990,41	505019,06	487143,10	469277,07	451411,23	433545,38	415712,91	501187,69	515232,27	529276,86	543321,45
Total energy	1799608,52	1642487,58	1611973,32	1681148,26	1848797,75	1657503,41	1787315,06	1694650,10	1600779,07	1505132,23	1414987,38	1343652,91	1708694,69	1722739,27	1736783,86	1750828,45
Total energy - induced energy	1025423,52	868302,58	837788,32	906959,26	1074612,75	883318,41	1013121,06	920455,10	826583,07	730935,23	640789,38	569453,91	813910,69	707356,27	630898,86	554441,45
% improvement EPG	0%	0%	0%	-26%	0%	0%	-86%	-48%	-22%	5%	29%	47%	-7%	34%	65%	96%
% improvement MPG	-1%	3%	6%	7%	-4%	1%	16%	20%	23%	27%	30%	34%	17%	14%	12%	9%
% improvement DPG	0%	3%	6%	2%	-3%	1%	3%	10%	17%	24%	30%	36%	14%	18%	20%	22%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
% improvement energy demand	0%	0%	0%	-7%	0%	0%	-20%	-13%	-6%	1%	8%	13%	-13%	-13%	-13%	-13%
% improvement embodied energy	-23%	4%	9%	10%	-31%	1%	16%	19%	22%	25%	28%	30%	16%	14%	12%	9%
% improvement total energy	-8%	1%	3%	-1%	-11%	0%	-7%	-2%	4%	10%	15%	19%	-3%	-3%	-4%	-5%

	Nature stone facade						Nature stone with PV on facade				Concrete facade						Concrete with PV on facade			
	100% open	80% open	60% open	40% open	20% open	0% open	114 Z	228 Z	228Z+114O	228Z+228O	100% open	80% open	60% open	40% open	20% open	0% open	114 Z	228 Z	228Z+114O	228Z+228O
Total CO2 EPG	31142,00	26558,00	21900,00	17132,00	12703,00	9424,00	19167,00	11775,00	6228,00	682,00	31142,00	26558,00	21900,00	17132,00	12703,00	9424,00	19167,00	11775,00	6228,00	682,00
Total CO2 MPG	35850,95	35805,28	35805,28	35759,61	35759,61	35713,94	36855,69	37860,43	38865,17	39869,91	36764,35	36170,64	35622,60	35074,56	34480,85	33932,81	37221,05	38088,78	38865,17	39961,25
Total CO2	66992,95	62363,28	57705,28	52891,61	48462,61	45137,94	56022,69	49635,43	45093,17	40551,91	67906,35	62728,64	57522,60	52206,56	47183,85	43356,81	56388,05	49863,78	45093,17	40643,25
EPG	0,34	0,29	0,24	0,19	0,14	0,10	0,21	0,13	0,07	0,01	0,34	0,29	0,24	0,19	0,14	0,10	0,21	0,13	0,07	0,01
MPG	0,95	0,93	0,92	0,91	0,89	0,87	0,97	1,00	1,03	1,07	1,01	0,97	0,93	0,90	0,86	0,83	1,00	1,03	1,06	1,09
DPG	1,29	1,22	1,16	1,10	1,03	0,97	1,18	1,13	1,10	1,08	1,35	1,26	1,17	1,09	1,00	0,93	1,21	1,16	1,13	1,10
EPG	0,34	0,29	0,24	0,19	0,14	0,10	0,21	0,13	0,07	0,01	0,34	0,29	0,24	0,19	0,14	0,10	0,21	0,13	0,07	0,01
CO2 part of DPG	0,73	0,68	0,63	0,58	0,53	0,49	0,61	0,54	0,49	0,44	0,74	0,69	0,63	0,57	0,52	0,47	0,62	0,55	0,49	0,44
% co2 van DPG	0,57	0,56	0,54	0,53	0,52	0,51	0,52	0,48	0,45	0,41	0,55	0,54	0,54	0,53	0,52	0,51	0,51	0,47	0,44	0,41
Energy demand	1282296,00	1207507,00	1131502,00	1053721,00	981442,00	927940,00	1207507,00	1207507,00	1207507,00	1207507,00	1282296,00	1207507,00	1131502,00	1053721,00	981442,00	927940,00	1207507,00	1207507,00	1207507,00	1207507,00
Energy demand - induced energy	508102,00	433312,00	357306,00	279524,00	207244,00	153741,00	312723,00	192124,00	101622,00	11120,00	508102,00	433312,00	357306,00	279524,00	207244,00	153741,00	312723,00	192124,00	101622,00	11120,00
Embodied energy	516086,61	507304,56	509513,48	509360,23	513820,55	516021,98	521349,15	521349,15	535393,73	572924,01	514799,78	501765,34	488756,57	475747,80	462739,03	449767,41	515809,93	529854,51	543899,10	557943,69
Total energy	1798382,61	1714811,56	1641015,48	1563081,23	1495262,55	1443961,98	1728856,15	1728856,15	1742900,73	1780431,01	1797095,78	1709272,34	1620258,57	1529468,80	1444181,03	1377707,41	1723316,93	1737361,51	1751406,10	1765450,69
Total energy - induced energy	1024188,61	940616,56	866819,48	788884,23	721064,55	669762,98	834072,15	713473,15	637015,73	584044,01	1022901,78	935077,34	846062,57	755271,80	669983,03	603508,41	828532,93	721978,51	645521,10	569063,69
% improvement EPG	-86%	-48%	-22%	5%	29%	47%	-7%	34%	65%	96%	-86%	-48%	-22%	5%	29%	47%	-7%	34%	65%	96%
% improvement MPG	15%	17%	18%	19%	21%	22%	13%	11%	8%	4%	10%	13%	17%	20%	23%	26%	11%	8%	5%	3%
% improvement DPG	2%	8%	12%	17%	22%	26%	11%	14%	17%	18%	-2%	4%	11%	18%	24%	29%	8%	12%	15%	17%
% improvement energy demand	-20%	-13%	-6%	1%	8%	13%	-13%	-13%	-13%	-13%	-20%	-13%	-6%	1%	8%	13%	-13%	-13%	-13%	-13%
% improvement embodied energy	14%	15%	15%	15%	14%	14%	13%	13%	10%	4%	14%	16%	18%	20%	23%	25%	14%	11%	9%	7%
% improvement total energy	-8%	-3%	1%	6%	10%	13%	-4%	-4%	-5%	-7%	-8%	-3%	3%	8%	13%	17%	-4%	-4%	-5%	-6%

1=roll normal 1,2=no lam 2=zip 2.2=zip no lam

	Sun shading														Transmission realistic	m2 BVO	
	1. Auto	1. Hand	1. Perm	1.2 Auto	1.2 Hand	1.2 Perm	1. Auto	2. Hand	2. Perm	2.2 Auto	2.2 Hand	2.2 Perm	2. Optimal	2.1 Optimal		10%	-10%
Total CO2 EPG	14353,00	14855,00	16476,00	14271,00	16825,00	16476,00	14353,00	14855,00	16476,00	14271,00	16825,00	16476,00	13054,33	10396,76	18713,00	21870,00	13451,00
Total CO2 MPG	47953,50	47953,50	47953,50	44071,55	44071,55	44071,55	47040,10	47040,10	47040,10	42929,80	42929,80	42929,80	47040,10	42929,80	44528,25	40509,29	49323,60
Total CO2	62306,50	62808,50	64429,50	58342,55	60896,55	60547,55	61393,10	61895,10	63516,10	57200,80	59754,80	59405,80	60094,43	53326,56	63241,25	62379,29	62774,60
EPG	0,16	0,16	0,18	0,16	0,18	0,18	0,16	0,16	0,18	0,16	0,18	0,18	0,14	0,11	0,20	0,24	0,15
MPG	1,45	1,45	1,45	1,37	1,37	1,37	1,23	1,23	1,23	1,15	1,15	1,15	1,23	1,15	1,12	1,02	1,25
DPG	1,61	1,61	1,63	1,53	1,55	1,55	1,39	1,39	1,41	1,31	1,33	1,33	1,37	1,26	1,32	1,26	1,40
EPG	0,16	0,16	0,18	0,16	0,18	0,18	0,16	0,16	0,18	0,16	0,18	0,18	0,14	0,11	0,20	0,24	0,15
CO2 part of DPG	0,68	0,69	0,71	0,64	0,67	0,66	0,67	0,68	0,70	0,63	0,65	0,65	0,66	0,58	0,69	0,68	0,69
% co2 van DPG	0,42	0,43	0,43	0,42	0,43	0,43	0,48	0,49	0,49	0,48	0,49	0,49	0,48	0,46	0,52	0,54	0,49
	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Energy demand	1008366,00	1016554,00	1043005,00	1007030,00	1048697,00	1043005,00	1008366,00	1016554,00	1043005,00	1007030,00	1048697,00	1043005,00	987160,00	943803,00	1079514,00	1067500,00	1064571,00
Energy demand - induced energy	234165,00	242352,00	268802,00	232829,00	274495,00	268802,00	234165,00	242352,00	268802,00	232829,00	274495,00	268802,00	212975,00	169618,00	305313,00	293297,00	290367,00
Embodied energy	660376,25	660376,25	660376,25	599512,77	599512,77	599512,77	649426,43	649426,43	649426,43	588587,09	588587,09	588587,09	649426,43	588587,09	598062,15	543659,12	664560,44
Total energy	1668742,25	1676930,25	1703381,25	1606542,77	1648209,77	1642517,77	1657792,43	1665980,43	1692431,43	1595617,09	1637284,09	1631592,09	1636586,43	1532390,09	1677576,15	1611159,12	1729131,44
Total energy - induced energy	894541,25	902728,25	929178,25	832341,77	874007,77	868314,77	883591,43	891778,43	918228,43	821416,09	863082,09	857389,09	862401,43	758205,09	903375,15	836956,12	954927,44
% improvement EPG	20%	17%	8%	20%	6%	8%	20%	17%	8%	20%	6%	8%	27%	42%	-4%	-14%	18%
% improvement MPG	-29%	-29%	-29%	-22%	-22%	-22%	-10%	-10%	-10%	-3%	-3%	-3%	-10%	-3%	0%	9%	-12%
% improvement DPG	-22%	-22%	-24%	-16%	-18%	-17%	-5%	-6%	-7%	1%	-1%	-1%	-4%	4%	0%	5%	-6%
% improvement energy demand	5%	5%	2%	6%	2%	2%	5%	5%	2%	6%	2%	2%	7%	12%	-1%	0%	0%
% improvement embodied energy	-10%	-10%	-10%	0%	0%	0%	-9%	-9%	-9%	2%	2%	2%	-9%	2%	0%	9%	-11%
% improvement total energy	0%	-1%	-2%	3%	1%	1%	0%	0%	-2%	4%	2%	2%	2%	8%	-1%	3%	-4%

	Height facade				Orientation			Service life						Circular	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	10%	20%	-10%	-20%	90 graden	180 graden	45 graden	25 years	50 years	75 years	100 years	125 years	150 years					
Total CO2 EPG	19083,00	20239,00	16738,00	15554,00	15307,00	17917,00	16957,00	17917,00	17917,00	17917,00	17917,00	17917,00	17917,00		17917,00	17917,00	18629,00	17917,00
Total CO2 MPG	45304,64	46583,40	42564,44	41194,34	44528,25	44528,25	44528,25	70788,50	44528,25	36627,34	34389,51	33065,08	32197,35		44528,25	88143,10	43706,19	42610,11
Total CO2	64387,64	66822,40	59302,44	56748,34	59835,25	62445,25	61485,25	88705,50	62445,25	54544,34	52306,51	50982,08	50114,35		62445,25	106060,10	62335,19	60527,11
EPG	0,21	0,22	0,18	0,17	0,17	0,20	0,19	0,20	0,20	0,20	0,20	0,20	0,20		0,20	0,20	0,20	0,20
MPG	1,14	1,18	1,08	1,04	1,12	1,12	1,12	1,73	1,12	0,94	0,89	0,86	0,84		1,12	2,15	1,09	1,07
DPG	1,35	1,40	1,26	1,21	1,29	1,32	1,31	1,93	1,32	1,14	1,09	1,06	1,04		1,32	2,35	1,29	1,27
EPG	0,21	0,22	0,18	0,17	0,17	0,20	0,19	0,20	0,20	0,20	0,20	0,20	0,20		0,20	0,20	0,20	0,20
CO2 part of DPG	0,70	0,73	0,65	0,62	0,66	0,68	0,67	0,97	0,68	0,60	0,57	0,56	0,55		0,68	1,16	0,68	0,66
% co2 van DPG	0,52	0,52	0,51	0,51	0,51	0,52	0,52	0,50	0,52	0,53	0,53	0,53	0,53		0,52	0,49	0,53	0,52
Energy demand	1089287,00	1111868,00	1043545,00	1020501,00	1023929,00	1066526,00	1050865,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00	1066513,00		1066513,00	1066513,00	1078139,00	1066513,00
Energy demand - induced energy	315081,00	337661,00	269338,00	246293,00	249720,00	292316,00	276654,00	292328,00	292327,00	292326,00	292325,00	292324,00	292323,00		292327,00	292327,00	303942,00	292327,00
Embodied energy	609594,31	628243,35	572296,25	553647,21	598062,15	598062,15	598062,15	916038,11	598062,15	505911,71	474250,02	455459,82	442760,67		598062,15	1139233,92	587152,54	572442,83
Total energy	1698881,31	1740111,35	1615841,25	1574148,21	1621991,15	1664588,15	1648927,15	1982551,11	1664575,15	1572424,71	1540763,02	1521972,82	1509273,67		1664575,15	2205746,92	1665291,54	1638955,83
Total energy - induced energy	924675,31	965904,35	841634,25	799940,21	847782,15	890378,15	874716,15	1208366,11	890389,15	798237,71	766575,02	747783,82	735083,67		890389,15	1431560,92	891094,54	864769,83
% improvement EPG	-6%	-13%	7%	13%	15%	0%	5%	0%	0%	0%	0%	0%	0%		0%	0%	-4%	0%
% improvement MPG	-2%	-5%	4%	7%	0%	0%	0%	-54%	0%	16%	21%	23%	25%		0%	-92%	3%	4%
% improvement DPG	-2%	-6%	4%	8%	2%	0%	1%	-46%	0%	14%	18%	20%	22%		0%	-78%	2%	4%
% improvement energy demand	-2%	-4%	2%	4%	4%	0%	1%	0%	0%	0%	0%	0%	0%		0%	0%	-1%	0%
% improvement embodied energy	-2%	-5%	4%	7%	0%	0%	0%	-53%	0%	15%	21%	24%	26%		0%	-90%	2%	4%
% improvement total energy	-2%	-5%	3%	5%	3%	0%	1%	-19%	0%	6%	7%	9%	9%		0%	-33%	0%	2%

APPENDIX G: NPV CALCULATIONS

energy demand (MJ)	1772096	1382421	1213680	1158657	1142564	1066513	1078139	1158710	1023183	1066513
delta energy (MJ)	705583	315908	147167	92144	76051	0	11626	92197	43330	0
delta energy (m3)	22293,30174	9981,295419	4649,826224	2911,342812	2402,875197	0	367,3301738	2913,017378	-1369,036335	0
embodied energy	515402	567182	559012	563443	564018	595.062	571688	533646	572897	562410
total energy	2.287.498	1.949.603	1.772.692	1.722.100	1.706.582	1.661.575	1.649.827	1.692.356	1.596.080	1.628.923
r 2%										
Aglass 2582 m2	single	double	HR	HR+	HR++	triple	triple 12 mm	vacuum	triple vacuum	triple+gorilla
Costs/ m2	€ 65,00	€ 115,00	€ 120,00	€ 125,00	€ 130,00	€ 170,00	€ 160,00	€ 250,00	€ 280,00	€ 300,00
Costs total	€ 167.830,00	€ 296.930,00	€ 309.840,00	€ 322.750,00	€ 335.660,00	€ 438.940,00	€ 413.120,00	€ 645.500,00	€ 722.960,00	€ 774.600,00
delta costs	€ 271.110,00	€ 142.010,00	€ 129.100,00	€ 116.190,00	€ 103.280,00	€ -	€ 25.820,00	€ -206.560,00	€ -284.020,00	€ -335.660,00
						REFERENCE				

31,65 MJ/m3

year	energiebel	energiepri	VAT	Total	NPV single glass	NPV double glass	NPV HR	NPV HR+	NPV HR++	NPV triple	NPV triple 12mm	NPV vacuum	NPV triple vacuum	NPV triple incl gorill
1	0,29	0,26	0,1155	0,6655	€ -251.248,83	€ -132.713,18	€ -123.534,84	€ -112.012,26	€ -99.687,14	€ -	€ -25.074,06	€ 204.410,40	€ 277.557,75	€ -329.078,43
2	0,33	0,26	0,1239	0,7139	€ -235.951,65	€ -125.864,23	€ -120.344,23	€ -110.014,56	€ -98.038,34	€ -	€ -24.822,01	€ 206.409,25	€ 276.618,35	€ -329.078,43
3	0,34	0,26	0,126	0,726	€ -220.700,22	€ -119.035,77	€ -117.163,17	€ -108.022,83	€ -96.394,47	€ -	€ -24.570,71	€ 208.402,13	€ 275.681,75	€ -329.078,43
4	0,35	0,26	0,1281	0,7381	€ -205.498,64	€ -112.229,62	€ -113.992,49	€ -106.037,61	€ -94.755,98	€ -	€ -24.320,23	€ 210.388,48	€ 274.748,22	€ -329.078,43
5	0,36	0,26	0,1302	0,7502	€ -190.350,80	€ -105.447,54	€ -110.833,03	€ -104.059,42	€ -93.123,27	€ -	€ -24.070,63	€ 212.367,82	€ 273.817,99	€ -329.078,43
6	0,37	0,26	0,1323	0,7623	€ -175.260,45	€ -98.691,19	€ -107.685,56	€ -102.088,73	€ -91.496,76	€ -	€ -23.821,99	€ 214.339,64	€ 272.891,29	€ -329.078,43
7	0,38	0,26	0,1344	0,7744	€ -160.231,16	€ -91.962,19	€ -104.550,83	€ -100.126,01	€ -89.876,84	€ -	€ -23.574,35	€ 216.303,49	€ 271.968,34	€ -329.078,43
8	0,39	0,26	0,1365	0,7865	€ -145.266,33	€ -85.262,04	€ -101.429,54	€ -98.171,71	€ -88.263,86	€ -	€ -23.327,77	€ 218.258,91	€ 271.049,34	€ -329.078,43
9	0,4	0,26	0,1386	0,7986	€ -130.369,21	€ -78.592,21	€ -98.322,37	€ -96.226,26	€ -86.658,18	€ -	€ -23.082,31	€ 220.205,48	€ 270.134,51	€ -329.078,43
10	0,41	0,26	0,1407	0,8107	€ -115.542,91	€ -71.954,09	€ -95.229,98	€ -94.290,05	€ -85.060,13	€ -	€ -22.838,01	€ 222.142,80	€ 269.224,02	€ -329.078,43
11	0,42	0,26	0,1428	0,8228	€ -100.790,37	€ -65.348,99	€ -92.152,97	€ -92.363,48	€ -83.470,03	€ -	€ -22.594,93	€ 224.070,49	€ 268.318,07	€ -329.078,43
12	0,43	0,26	0,1449	0,8349	€ -86.114,40	€ -58.778,17	€ -89.091,92	€ -90.446,90	€ -81.888,19	€ -	€ -22.353,12	€ 225.988,16	€ 267.416,81	€ -329.078,43
13	0,44	0,26	0,147	0,847	€ -71.517,67	€ -52.242,83	€ -86.047,41	€ -88.540,68	€ -80.314,89	€ -	€ -22.112,60	€ 227.895,49	€ 266.520,42	€ -329.078,43
14	0,45	0,26	0,1491	0,8591	€ -57.002,72	€ -45.744,11	€ -83.019,95	€ -86.645,13	€ -78.750,40	€ -	€ -21.873,44	€ 229.792,12	€ 265.629,06	€ -329.078,43
15	0,46	0,26	0,1512	0,8712	€ -42.571,94	€ -39.283,07	€ -80.010,05	€ -84.760,57	€ -77.194,98	€ -	€ -21.635,66	€ 231.677,76	€ 264.742,86	€ -329.078,43
16	0,47	0,26	0,1533	0,8833	€ -28.227,62	€ -32.860,75	€ -77.018,19	€ -82.887,31	€ -75.648,89	€ -	€ -21.399,31	€ 233.552,10	€ 263.861,97	€ -329.078,43
17	0,48	0,26	0,1554	0,8954	€ -13.971,92	€ -26.478,09	€ -74.044,80	€ -81.025,62	€ -74.112,34	€ -	€ -21.164,41	€ 235.414,86	€ 262.986,53	€ -329.078,43
18	0,49	0,26	0,1575	0,9075	€ 193,12	€ -20.136,03	€ -71.090,33	€ -79.175,77	€ -72.585,57	€ -	€ -20.931,01	€ 237.265,78	€ 262.116,65	€ -329.078,43
19	0,5	0,26	0,1596	0,9196	€ 14.265,58	€ -13.835,42	€ -68.155,17	€ -77.338,01	€ -71.068,77	€ -	€ -20.699,14	€ 239.104,60	€ 261.252,46	€ -329.078,43
20	0,51	0,26	0,1617	0,9317	€ 28.243,65	€ -7.577,08	€ -65.239,69	€ -75.512,57	€ -69.562,15	€ -	€ -20.468,82	€ 240.931,08	€ 260.394,06	€ -329.078,43
21	0,52	0,26	0,1638	0,9438	€ 42.125,61	€ -1.361,76	€ -62.344,26	€ -73.699,69	€ -68.065,89	€ -	€ -20.240,08	€ 242.745,01	€ 259.541,57	€ -329.078,43
22	0,53	0,26	0,1659	0,9559	€ 55.909,85	€ 4.809,81	€ -59.469,21	€ -71.899,57	€ -66.580,16	€ -	€ -20.012,96	€ 244.546,16	€ 258.695,07	€ -329.078,43
23	0,54	0,26	0,168	0,968	€ 69.594,89	€ 10.936,96	€ -56.614,85	€ -70.112,40	€ -65.105,12	€ -	€ -19.787,47	€ 246.334,36	€ 257.854,67	€ -329.078,43
24	0,55	0,26	0,1701	0,9801	€ 83.179,29	€ 17.019,05	€ -53.781,49	€ -68.338,38	€ -63.640,93	€ -	€ -19.563,64	€ 248.109,40	€ 257.020,45	€ -329.078,43
25	0,56	0,26	0,1722	0,9922	€ 96.661,76	€ 23.055,50	€ -50.969,38	€ -66.577,67	€ -62.187,73	€ -	€ -19.341,48	€ 249.871,13	€ 256.192,49	€ -329.078,43
26	0,57	0,26	0,1743	1,0043	€ 110.041,06	€ 29.045,77	€ -48.178,79	€ -64.830,43	€ -60.745,65	€ -	€ -19.121,03	€ 251.619,37	€ 255.370,86	€ -329.078,43
27	0,58	0,26	0,1764	1,0164	€ 123.316,05	€ 34.989,33	€ -45.409,96	€ -63.096,81	€ -59.314,81	€ -	€ -18.902,30	€ 253.353,99	€ 254.555,64	€ -329.078,43
28	0,59	0,26	0,1785	1,0285	€ 136.485,69	€ 40.885,72	€ -42.663,10	€ -61.376,95	€ -57.895,32	€ -	€ -18.685,30	€ 255.074,83	€ 253.746,89	€ -329.078,43
29	0,6	0,26	0,1806	1,0406	€ 149.549,00	€ 46.734,51	€ -39.938,42	€ -59.670,98	€ -56.487,30	€ -	€ -18.470,05	€ 256.781,79	€ 252.944,67	€ -329.078,43
30	0,61	0,26	0,1827	1,0527	€ 162.505,09	€ 52.535,29	€ -37.236,10	€ -57.979,01	€ -55.090,83	€ -	€ -18.256,57	€ 258.474,73	€ 252.149,04	€ -329.078,43
31	0,62	0,26	0,1848	1,0648	€ 175.353,14	€ 58.287,70	€ -34.556,32	€ -56.301,15	€ -53.706,01	€ -	€ -18.044,87	€ 260.153,56	€ 251.360,03	€ -329.078,43
32	0,63	0,26	0,1869	1,0769	€ 188.092,40	€ 63.991,40	€ -31.899,23	€ -54.637,49	€ -52.332,91	€ -	€ -17.834,97	€ 261.818,17	€ 250.577,71	€ -329.078,43
33	0,64	0,26	0,189	1,089	€ 200.722,20	€ 69.646,09	€ -29.264,97	€ -52.988,13	€ -50.971,61	€ -	€ -17.626,86	€ 263.468,48	€ 249.802,12	€ -329.078,43
34	0,65	0,26	0,1911	1,1011	€ 213.241,94	€ 75.251,51	€ -26.653,66	€ -51.353,14	€ -49.622,18	€ -	€ -17.420,57	€ 265.104,41	€ 249.033,28	€ -329.078,43
35	0,66	0,26	0,1932	1,1132	€ 225.651,08	€ 80.807,40	€ -24.065,43	€ -49.732,60	€ -48.284,66	€ -	€ -17.216,11	€ 266.725,88	€ 248.271,23	€ -329.078,43
36	0,67	0,26	0,1953	1,1253	€ 237.949,14	€ 86.313,57	€ -21.500,36	€ -48.126,56	€ -46.959,12	€ -	€ -17.013,47	€ 268.332,84	€ 247.516,00	€ -329.078,43
37	0,68	0,26	0,1974	1,1374	€ 250.135,70	€ 91.769,81	€ -18.958,55	€ -46.535,09	€ -45.645,60	€ -	€ -16.812,67	€ 269.925,23	€ 246.767,62	€ -329.078,43
38	0,69	0,26	0,1995	1,1495	€ 262.210,42	€ 97.175,98	€ -16.440,06	€ -44.958,22	€ -44.344,13	€ -	€ -16.613,71	€ 271.503,01	€ 246.026,11	€ -329.078,43
39	0,7	0,26	0,2016	1,1616	€ 274.172,98	€ 102.531,93	€ -13.944,97	€ -43.396,00	€ -43.054,75	€ -	€ -16.416,60	€ 273.066,13	€ 245.291,49	€ -329.078,43
40	0,71	0,26	0,2037	1,1737	€ 286.023,15	€ 107.837,56	€ -11.473,32	€ -41.848,45	€ -41.777,48	€ -	€ -16.221,35	€ 274.614,57	€ 244.563,77	€ -329.078,43
41	0,72	0,26	0,2058	1,1858	€ 297.760,74	€ 113.092,79	€ -9.025,15	€ -40.315,61	€ -40.512,35	€ -	€ -16.027,95	€ 276.148,29	€ 243.842,96	€ -329.078,43
42	0,73	0,26	0,2079	1,1979	€ 309.385,60	€ 118.297,54	€ -6.600,50	€ -38.797,48	€ -39.259,37	€ -	€ -15.836,40	€ 277.667,29	€ 243.129,07	€ -329.078,43
43	0,74	0,26	0,21	1,21	€ 320.897,64	€ 123.451,79	€ -4.199,37	€ -37.294,09	€ -38.018,55	€ -	€ -15.646,71	€ 279.171,54	€ 242.422,12	€ -329.078,43
44	0,75	0,26	0,2121	1,2221	€ 332.296,82	€ 128.555,50	€ -1.821,79	€ -35.805,45	€ -36.789,89	€ -	€ -15.458,89	€ 280.661,05	€ 241.722,09	€ -329.078,43
45	0,76	0,26	0,2142	1,2342	€ 343.583,14	€ 133.608,68	€ 532,26	€ -34.331,53	€ -35.573,40	€ -	€ -15.272,92	€ 282.135,81	€ 241.029,00	€ -329.078,43
46	0,77	0,26	0,2163	1,2463	€ 354.756,63	€ 138.611,34	€ 2.862,77	€ -32.872,36	€ -34.369,07	€ -	€ -15.088,81	€ 283.595,82	€ 240.342,83	€ -329.078,43
47	0,78	0,26	0,2184	1,2584	€ 365.817,39	€ 143.563,54	€ 5.169,77	€ -31.427,90	€ -33.176,89	€ -	€ -14.906,57	€ 285.041,11	€ 239.663,59	€ -329.078,43
48	0,79	0,26	0,2205	1,2705	€ 376.765,55	€ 148.465,31	€ 7.453,28	€ -29.998,15	€ -31.996,85	€ -	€ -14.726,17	€ 286.471,68	€ 238.991,26	€ -329.078,43
49	0,8	0,26	0,2226	1,2826	€ 387.601,25	€ 153.316,74	€ 9.713,34	€ -28.583,09	€ -30.828,93	€ -	€ -14.547,63	€ 287.887,56	€ 238.325,83	€ -329.078,43
50	0,81	0,26	0,2247	1,2947	€ 398.324,71	€ 158.117,91	€ 11.949,98	€ -27.182,68	€ -29.673,10	€ -	€ -14.370,94	€ 289.288,77	€ 237.667,30	€ -329.078,43

					0	49.104,00	90.491,00	120.588,00	89.505,00	169.703,00	241.187,00	331.689,00	422.191,00
					774196	823.300	864.687	894.784	863.701	943.899	1.015.383	1.105.885	1.196.387
energy demand (MJ)					1066513	1066513	1066513	1066513	1066513	1066513	1066513	1066513	1066513
delta energy (MJ)					1.066.513,00	1.017.409,00	976.022,00	945.925,00	977.008,00	896.810,00	825.326,00	734.824,00	644.322,00
delta energy (m3)					-	1.551,47	2.859,12	3.810,05	2.827,96	5.361,86	7.620,44	10.479,91	13.339,37
r	2%				No PV on facade	144m2 N	144m2 O	144m2 Z	144m2 W	228 Z+O	228 Z	342 (228 Z+ 114 O	456 (228 Z+228 O)
Aglass	2582				0	114,00	114,00	114,00	114,00	228,00	228,00	342,00	456,00
Costs/ m2					€ 250,00	€ 250,00	€ 250,00	€ 250,00	€ 250,00	€ 250,00	€ 250,00	€ 250,00	€ 250,00
Costs total					€ -	€ 28.500,00	€ 28.500,00	€ 28.500,00	€ 28.500,00	€ 57.000,00	€ 57.000,00	€ 85.500,00	€ 114.000,00
					REFERENCE								
		31,65	MJ/m3										
year	energiebel	energiepri	VAT	Total									
1	0,29	0,26	0,1155	0,6655	-	€ -26.928,92	€ -26.075,74	€ -25.455,31	€ -26.096,07	€ -52.384,00	€ -50.910,39	€ -76.985,90	€ -103.061,42
2	0,33	0,26	0,1239	0,7139	-	€ -25.864,33	€ -24.113,88	€ -22.840,94	€ -24.155,58	€ -48.704,80	€ -45.681,40	€ -69.794,82	€ -93.908,24
3	0,34	0,26	0,126	0,726	-	€ -24.799,75	€ -22.152,02	€ -20.226,56	€ -22.215,10	€ -45.025,61	€ -40.452,42	€ -62.603,74	€ -84.755,05
4	0,35	0,26	0,1281	0,7381	-	€ -23.738,35	€ -20.196,02	€ -17.620,01	€ -20.280,41	€ -41.357,42	€ -35.239,08	€ -55.434,16	€ -75.629,24
5	0,36	0,26	0,1302	0,7502	-	€ -22.680,42	€ -18.246,42	€ -15.021,98	€ -18.352,05	€ -37.701,21	€ -30.042,77	€ -48.288,01	€ -66.533,26
6	0,37	0,26	0,1323	0,7623	-	€ -21.626,23	€ -16.303,71	€ -12.433,13	€ -16.430,51	€ -34.057,94	€ -24.864,84	€ -41.167,14	€ -57.469,43
7	0,38	0,26	0,1344	0,7744	-	€ -20.576,04	€ -14.368,37	€ -9.854,10	€ -14.516,26	€ -30.428,49	€ -19.706,56	€ -34.073,28	€ -48.440,01
8	0,39	0,26	0,1365	0,7865	-	€ -19.530,09	€ -12.440,87	€ -7.285,52	€ -12.609,76	€ -26.813,73	€ -14.569,15	€ -27.008,13	€ -39.447,11
9	0,4	0,26	0,1386	0,7986	-	€ -18.488,64	€ -10.521,63	€ -4.727,94	€ -10.711,43	€ -23.214,47	€ -9.453,77	€ -19.973,28	€ -30.492,79
10	0,41	0,26	0,1407	0,8107	-	€ -17.451,90	€ -8.611,07	€ -2.181,95	€ -8.821,70	€ -19.631,49	€ -4.361,54	€ -12.970,27	€ -21.578,99
11	0,42	0,26	0,1428	0,8228	-	€ -16.420,08	€ -6.709,60	€ 351,95	€ -6.940,94	€ -16.065,55	€ 706,48	€ -6.000,54	€ -12.707,56
12	0,43	0,26	0,1449	0,8349	-	€ -15.393,40	€ -4.817,59	€ 2.873,24	€ -5.069,54	€ -12.517,35	€ 5.749,29	€ 934,51	€ -3.880,26
13	0,44	0,26	0,147	0,847	-	€ -14.372,05	€ -2.935,39	€ 5.381,44	€ -3.207,86	€ -8.987,57	€ 10.765,93	€ 7.833,57	€ 4.901,22
14	0,45	0,26	0,1491	0,8591	-	€ -13.356,21	€ -1.063,36	€ 7.876,10	€ -1.356,23	€ -5.476,84	€ 15.755,48	€ 14.695,38	€ 13.635,28
15	0,46	0,26	0,1512	0,8712	-	€ -12.346,06	€ 798,18	€ 10.356,79	€ 485,03	€ -1.985,78	€ 20.717,07	€ 21.518,74	€ 22.320,42
16	0,47	0,26	0,1533	0,8833	-	€ -11.341,78	€ 2.648,92	€ 12.823,09	€ 2.315,61	€ 1.485,03	€ 25.649,90	€ 28.302,54	€ 30.955,18
17	0,48	0,26	0,1554	0,8954	-	€ -10.343,50	€ 4.488,58	€ 15.274,61	€ 4.135,22	€ 4.935,05	€ 30.553,16	€ 35.045,69	€ 39.538,21
18	0,49	0,26	0,1575	0,9075	-	€ -9.351,40	€ 6.316,88	€ 17.710,99	€ 5.943,60	€ 8.363,75	€ 35.426,14	€ 41.747,18	€ 48.068,22
19	0,5	0,26	0,1596	0,9196	-	€ -8.365,61	€ 8.133,54	€ 20.131,87	€ 7.740,47	€ 11.770,65	€ 40.268,13	€ 48.406,06	€ 56.543,98
20	0,51	0,26	0,1617	0,9317	-	€ -7.386,25	€ 9.938,34	€ 22.536,93	€ 9.525,60	€ 15.155,28	€ 45.078,47	€ 55.021,41	€ 64.964,35
21	0,52	0,26	0,1638	0,9438	-	€ -6.413,47	€ 11.731,02	€ 24.925,86	€ 11.298,75	€ 18.517,21	€ 49.856,54	€ 61.592,39	€ 73.328,23
22	0,53	0,26	0,1659	0,9559	-	€ -5.447,38	€ 13.511,38	€ 27.298,36	€ 13.059,71	€ 21.856,03	€ 54.601,77	€ 68.118,19	€ 81.634,61
23	0,54	0,26	0,168	0,968	-	€ -4.488,08	€ 15.279,21	€ 29.654,17	€ 14.808,28	€ 25.171,34	€ 59.313,59	€ 74.598,05	€ 89.882,52
24	0,55	0,26	0,1701	0,9801	-	€ -3.535,69	€ 17.034,32	€ 31.993,01	€ 16.544,26	€ 28.462,79	€ 63.991,49	€ 81.031,28	€ 98.071,06
25	0,56	0,26	0,1722	0,9922	-	€ -2.590,31	€ 18.776,52	€ 34.314,66	€ 18.267,48	€ 31.730,04	€ 68.635,01	€ 87.417,20	€ 106.199,40
26	0,57	0,26	0,1743	1,0043	-	€ -1.652,01	€ 20.505,64	€ 36.618,89	€ 19.977,76	€ 34.972,77	€ 73.243,67	€ 93.755,20	€ 114.266,73
27	0,58	0,26	0,1764	1,0164	-	€ -720,90	€ 22.221,54	€ 38.905,49	€ 21.674,96	€ 38.190,68	€ 77.817,07	€ 100.044,70	€ 122.272,34
28	0,59	0,26	0,1785	1,0285	-	€ 202,95	€ 23.924,06	€ 41.174,26	€ 23.358,93	€ 41.383,51	€ 82.354,82	€ 106.285,18	€ 130.215,54
29	0,6	0,26	0,1806	1,0406	-	€ 1.119,47	€ 25.613,06	€ 43.425,02	€ 25.029,53	€ 44.551,00	€ 86.856,55	€ 112.476,12	€ 138.095,69
30	0,61	0,26	0,1827	1,0527	-	€ 2.028,60	€ 27.288,43	€ 45.657,61	€ 26.686,64	€ 47.692,92	€ 91.321,93	€ 118.617,08	€ 145.912,22
31	0,62	0,26	0,1848	1,0648	-	€ 2.930,25	€ 28.950,05	€ 47.871,88	€ 28.330,16	€ 50.809,05	€ 95.750,67	€ 124.707,63	€ 153.664,60
32	0,63	0,26	0,1869	1,0769	-	€ 3.824,40	€ 30.597,81	€ 50.067,68	€ 29.959,96	€ 53.899,19	€ 100.142,47	€ 130.747,40	€ 161.352,32
33	0,64	0,26	0,189	1,089	-	€ 4.710,97	€ 32.231,62	€ 52.244,89	€ 31.575,97	€ 56.963,17	€ 104.497,09	€ 136.736,02	€ 168.974,96
34	0,65	0,26	0,1911	1,1011	-	€ 5.589,92	€ 33.851,39	€ 54.403,39	€ 33.178,09	€ 60.000,82	€ 108.814,29	€ 142.673,20	€ 176.532,10
35	0,66	0,26	0,1932	1,1132	-	€ 6.461,21	€ 35.457,05	€ 56.543,08	€ 34.766,25	€ 63.012,00	€ 113.093,87	€ 148.558,63	€ 184.023,38
36	0,67	0,26	0,1953	1,1253	-	€ 7.324,81	€ 37.048,52	€ 58.663,87	€ 36.340,38	€ 65.996,58	€ 117.335,64	€ 154.392,06	€ 191.448,48
37	0,68	0,26	0,1974	1,1374	-	€ 8.180,67	€ 38.625,75	€ 60.765,68	€ 37.900,42	€ 68.954,44	€ 121.539,45	€ 160.173,28	€ 198.807,12
38	0,69	0,26	0,1995	1,1495	-	€ 9.028,78	€ 40.188,67	€ 62.848,43	€ 39.446,32	€ 71.885,49	€ 125.705,14	€ 165.902,09	€ 206.099,05
39	0,7	0,26	0,2016	1,1616	-	€ 9.869,10	€ 41.737,25	€ 64.912,06	€ 40.978,03	€ 74.789,63	€ 129.832,60	€ 171.578,32	€ 213.324,04
40	0,71	0,26	0,2037	1,1737	-	€ 10.701,62	€ 43.271,45	€ 66.956,53	€ 42.495,51	€ 77.666,80	€ 133.921,72	€ 177.201,83	€ 220.481,94
41	0,72	0,26	0,2058	1,1858	-	€ 11.526,31	€ 44.791,24	€ 68.981,79	€ 43.998,74	€ 80.516,94	€ 137.972,42	€ 182.772,50	€ 227.572,58
42	0,73	0,26	0,2079	1,1979	-	€ 12.343,17	€ 46.296,58	€ 70.987,81	€ 45.487,68	€ 83.340,00	€ 141.984,64	€ 188.290,25	€ 234.595,85
43	0,74	0,26	0,21	1,21	-	€ 13.152,19	€ 47.787,47	€ 72.974,56	€ 46.962,32	€ 86.135,95	€ 145.958,33	€ 193.755,00	€ 241.551,68
44	0,75	0,26	0,2121	1,2221	-	€ 13.953,35	€ 49.263,89	€ 74.942,03	€ 48.422,65	€ 88.904,77	€ 149.893,45	€ 199.166,72	€ 248.439,99
45	0,76	0,26	0,2142	1,2342	-	€ 14.746,66	€ 50.725,83	€ 76.890,21	€ 49.868,67	€ 91.646,43	€ 153.789,99	€ 204.525,38	€ 255.260,78
46	0,77	0,26	0,2163	1,2463	-	€ 15.532,11	€ 52.173,30	€ 78.819,11	€ 51.300,37	€ 94.360,96	€ 157.647,95	€ 209.830,99	€ 262.014,03
47	0,78	0,26	0,2184	1,2584	-	€ 16.309,72	€ 53.606,30	€ 80.728,72	€ 52.717,75	€ 97.048,35	€ 161.467,35	€ 215.083,57	€ 268.699,78
48	0,79	0,26	0,2205	1,2705	-	€ 17.079,47	€ 55.024,85	€ 82.619,06	€ 54.120,84	€ 99.708,62	€ 165.248,21	€ 220.283,14	€ 275.318,07
49	0,8	0,26	0,2226	1,2826	-	€ 17.841,39	€ 56.428,95	€ 84.490,16	€ 55.509,64	€ 102.341,81	€ 168.990,58	€ 225.429,78	€ 281.868,98
50	0,81	0,26	0,2247	1,2947	-	€ 18.595,49	€ 57.818,62	€ 86.342,04	€ 56.884,18	€ 104.947,96	€ 172.694,51	€ 230.523,56	€ 288.352,61