Decision-Making on the Sustainable Development of Office Buildings

Improving the balance between the value areas People, Planet and Profit given the objectives of the organization

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Colophon

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Preface

It was difficult for me to frame what subject my research was going to be about, many subjects caught my attention and interest. But when I came across this subject, I knew that this was a great opportunity and I wanted held my graduation research about this subject. A subject in which I could combine my architectural and real estate background with my current Master education Construction Management and Engineering.

The result is this MSc graduation thesis. For me a very special document because it officially ends my time as a student. Here I have received a lot of baggage which I will further add in practice, because every day you learn something new in life. I found the last period very instructive in which I have developed my scientific side. I am therefore proud of the result and wish you much pleasure in reading my research.

Through this way I want to thank a number of people, starting with my supervisors from the Technical University in Delft. The gentlemen Luscuere, de Graaf and Jonkers, with their expertise and critical approaches, have ensured that this Master's thesis has become a product that has surpassed my own expectations. I would also like to thank my supervisor, Jaap Koek, for his time and expertise as a client, just like Joost Verploegen who gave me the opportunity to carry out this research for such a beautiful building as in the Haagse Arc. Finally, I would like to thank my friends, family and especially my parents and my wife for the moral support and their belief in me as a person.

Kağan Gezgin
The Hague, July 2018

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Summary

The Dutch government has issued a legislation that follows the Paris Agreement of 2016. This legislation means that all office buildings in 2023 must have minimum energy label C while the ambition in 2030 is to have energy label A and in 2050 zero energy buildings. It is estimated that currently more than half of the office buildings in the Netherlands must take measures to meet this upcoming obligation before 2023. Investments must be made by office building owners to meet these energy labels while they have not taken these investments into account (financially). Furthermore owners do not have the (necessary) knowledge regarding energy labels and sustainability. Office building owners want to know whether investments can be made from a broader sustainability perspective within the value areas People, Planet and Profit that are also financially justified. To know this office building owners need to be facilitated knowledge and insight in the effects and opportunities of sustainability measures.

The main goal of this research is to determine whether more insight in the effects of sustainability measures, by translating this to People, Planet & Profit, will contribute in achieving a higher return on investment in the renovation of office buildings. To do so, the following research question is formulated:

How can an office building owner make informed decisions on the sustainable development of his building to achieve minimum energy label C, resulting in an improved balance between the value areas People, Planet and Profit given the objectives of the organization?

Currently there are around 67.500 office buildings in the Netherlands. These buildings have a total of 85 million m² of floor space. Estimation is that almost 47,4% of the current office supply will already have an energy label of C or higher. Therefore this mandatory law affects 52,6% of the current office supply. Office buildings has the largest energy savings potential (22%) within the service sector in the Netherlands.

This research maintains the triple bottom line theory by John Elkington (1994). The People dimension refers to the indoor environmental quality (IEQ) and the impact this has on the users of the building which are for the most part employees. The Planet dimension stands for the energy use of the office building. And the Profit dimension is about creating economic value with the sustainability measures. Also, the impact that the IEQ has in terms of health, productivity and performance is elaborated which can be seen as opportunities and threats. These opportunities can be divided into technical, financial and organizational opportunities. Savings in up to 18 m³ gas and 29 kWh electricity usage per m², lifetime extension, perspective towards energy label A and modern technique are technical opportunities. Increase in rent price and market value, lower energy costs from 1 till 13 € per m² per year, financing and subsidy are the financial opportunities. More control, strengthen competitive position, attract tenants and their employees and a better work environment are organizational opportunities.

To realise these opportunities, sustainability measures are given in 8 different categories. These categories are Insulation façade, Insulation floor, Insulation roof, Glazing windows and blinds, Heating, Cooling, Ventilation and Lighting. For each category, the effect on the IEQ and People dimension are given. These measures can be used to determine the possible sustainability measures (packages) for a specific building. But the decision making in which measures to invest is a big question mark for the building owner. Therefore a model is designed which will help the building owners in the decision making process. The objective of the model is to enable mathematical operations on different elements. By using the model, office building owners consider their own organizational interests and objectives within the dimensions People, Planet & Profit. This is done in a so-called weighting process of the different dimensions and their criteria. This will lead that informed decisions can be made on the sustainable development of the building which fits the best between the value areas People, Planet and Profit given the objectives of the organization or client.

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1. Introduction

1.1 Current situation

On 22 April 2016, the Paris Agreement was opened for signature at UN Headquarters in New York. The Paris Agreement (United Nations, 2018) aims (1) to strengthen the global response to the threat of climate change by keeping a global temperature rise below 2 degrees, (2) increase the ability of countries to deal with the impacts of climate change, (3) and at making finance flows consistent with a low greenhouse gas emissions and increases climate resiliency. It entered into force on 4 November 2016 when the agreement became official international law.

The European Union (EU) adopted this in the development of their climate strategies and targets (European Commission, 2011). This resulted in the 2020 climate and energy package, the 2030 climate and energy framework, and the 2050 low-carbon economy road map. The main target is to bring down greenhouse gas emissions by 20%, 40%, 60% (milestone in 2040) and 80% below 1990 levels. There are also targets for the increase of renewable energy and increase of energy efficiency which are both 20% related to 1990 levels. EU countries are forced to act to reach these new targets. The greatest energy saving potential lies in buildings, making old and new buildings more energy efficient helps the EU achieve its energy and climate goals. Buildings are responsible for 40% of energy consumption and 36% of CO2 emissions in the EU.

In the Netherlands about ⅓ of the total energy consumption is consumed by the building environment. The Dutch government composed a plan of action (European Commission, 2018) that stimulates energy savings. The ambition is to have zero energy buildings in the year of 2050. From the date of 2023, each office building larger than 100 m² must meet the new legislation of having an energy label of at least C (Blok, 2016). Also the ambition in the legislation is to have all office buildings got energy label A in 2030. It is estimated that more than half of the office buildings in the Netherlands must take measures to meet this upcoming obligation before 2023 (de Vries & Roskam, 2017). Therefore, this research focuses on the Dutch office building stock.

Sustainability

Nowadays, sustainability is a term that is used in different ways. According to Johnston, Everard, Santillo and Robèrt (2007), there are about three hundred definitions of sustainability. For this reason, a clear definition is needed to be maintained in this research. This research maintains the definition of sustainability by John Elkington (1994), who developed the triple bottom line theory. This theory is also known as the 3P's: People, Planet and Profit. His definition indicates that sustainability is a balance between these three P's.

In this research, the dimension People stands for the care of the users of the office building and in its surroundings. This is determined by the IEQ (indoor environmental quality) of the building, which influences the health, productivity and performance of the users. The planet dimension refers to the energy performance of the building and indirectly the damage that is caused to its surroundings and to the planet. The Profit dimension points to the financial aspect in order to make the building sustainable.

Office building stock

To get an idea of the size of Dutch office buildings, some key figures are presented in table 1. According to a reference image of ECN the total use within the services sector in the Netherlands of gas is 181 PJ and electricity is 128 PJ. Office buildings contribute 20% on the total of gas and 19% on the usage of electricity while it only uses 18% of the total m² supply. Office buildings can contribute to the saving potential with the largest amount of 22%.

OFFICE BUILDINGS	
CURRENT SITUATION	
SUPPLY	85.000.000 m²
SHARE MONUMENT	3.300.000 m²
AMOUNT	67.500
ENERGY LABEL C OR HIGHER	11.625 (17%)
ENERGY LABEL D OR BELOW	20.303 (30%)
ESTIMATION	
ENERGY LABEL C OR HIGHER	47,4% of total supply
ENERGY LABEL D OR BELOW	52,6% of total supply

Table 1 Key figures office buildings (Arnoldussen, van Zwet, Koning, & Menkveld, 2016)

Current situation building owners

Office building owners who only rent out their building are not willing to make improvements in their building. This is because they see it as extra costs within their financial planning and with little direct benefits. The biggest advantage is for the tenant who will have lower energy consumption, but the willingness of the tenant to pay more rent is minimum. Especially relatively small companies don't see the overall benefits of these changes. But building owners realise that there is a need to change in order to compete with other office buildings. They want to gain insight into which measures they can take to realise the best return on investment.

Triple bottom line

The triple bottom line (3BL) was first thought by John Elkington in 1994 and describes it as People, Planet and Profit and also the goal of sustainability. The 3BL consists of social equity, economic and environmental factors (Kuhlman & Farrington, 2010):

- People (or social equity): People stand for the care for the employees within the organization.
- Planet (or environmental bottom line): Planet stands for contributing to solving environmental problems that the organization has or can have an influence on.
- Profit (or economic bottom line): Profit is about creating (economic) value.

When we relate these terms with the sustainability measures, the benefits can be categorized within the 3BL. Below we will give what will be understood by these terms related to the sustainability measures.

- People: Indoor environmental quality of the building and indirect social and environmental effects. These may affect the working atmosphere of the employees and health.
- Planet: Energy usage of the building with corresponding energy label.
- Profit: (In)direct (Economic) Value which has been created with the sustainability measures.

1.2 Research problem

From the sketch of the current situation, four issues regarding office buildings have come to light:

1. Need for energy efficiency improvements, partly stimulated by international law.
2. First interventions need to result in an energy label C before 2023. Upcoming ambition is an energy label A by 2030 and zero energy buildings by 2050
3. Financially, these interventions have not been taken into account and are seen as a cost item with no direct benefits for the owner of the building but only for the tenant which will result in a lower energy bill.
4. Owners don't have the knowledge regarding energy labels and sustainability. They are not aware of the opportunities linked to people, planet and profit.

To deal with these four issues, office buildings must become more sustainable as defined for this study. To do so, the following problem statement has been used:

Climate strategies and targets pressure countries to improve energy efficiency. In the Netherlands, this should largely be achieved in Dutch office buildings. This is partly included in legislation for the year 2023 and will be continued in upcoming years with the ambition to have zero energy buildings by 2050. Nowadays, more than half of the office buildings do not meet the requirements of the government. Investments must be made by office building owners to meet these energy labels while they have not taken these investments into account (financially). Furthermore owners do not have the (necessary) knowledge regarding energy labels and sustainability. Office building owners want to know whether investments can be made from a broader sustainability perspective within the value areas People, Planet and Profit that are also financially justified. To know this office building owners need to be facilitated knowledge and insight in the effects and opportunities of sustainability measures.

1.3 Research goals

The main goal of this research is to determine whether more insight in the effects of sustainability measures, by translating this to People, Planet & Profit, will contribute in achieving a higher return on investment in the renovation of office buildings. To do so, the following research goals are formulated.

1. Provide office buildings owners with knowledge and insights in the technical, financial and organizational opportunities in renovation projects. By making the effects transparent through People, Planet & Profit. Owners are expected (by myself) to take measures which will lead to higher sustainability.
2. Determine qualitative and quantitative expectations of the effects of interventions.

1.4 Research question

Given the formulated problem statement and research goals, The following main research question is formulated.

> *How can an office building owner make informed decisions on the sustainable development of his building to achieve minimum energy label C, resulting in an improved balance between the value areas People, Planet and Profit given the objectives of the organization?*

Answering sub-questions will contribute to the answer of the main research question. The sub-questions are formulated below:

1. What is the current state of the Dutch office building stock?
2. What does sustainability mean for office buildings?
3. What are the (subsidy) opportunities in office building renovation and what does an improved energy label mean in terms of People, Planet & Profit?
4. What generic (combination of) technical sustainability measures can improve the sustainability and what effect will it have in terms of People, Planet & Profit?
5. How can technical, financial and organizational opportunities be evaluated by office building owners?
6. To what extent does insight in effects of sustainability measures result in improved return on investment?

1.5 Research scope

This research focuses solely on existing Dutch office buildings because of reason that new office buildings are already built with an energy label C or higher (mostly A) and don't have to deal with this new regulation. Sustainability measures are measures which affect the 'shell' of the building or are part of the technical installation of the building. These are considered when these also improve the energy label. Other changes such as occupant behaviour, interior and ground plan are not part of this research. The sustainable measure packages affect the indoor environmental quality on parts as founded in the desk research. Energy label effects will be calculated using approved software which is used to put out an energy label. These outcomes will not be discussed whether this is in line with the actual energy usage.

1.6 Research methods

This section describes the research methods used to provide an answer to the research questions. For each research method, the (expected) findings are presented.

Preliminary interviews

The research started with an investigation into the upcoming legislation that (office) buildings will need to improve their energy label to minimum C in 2023. When this investigation lead to problems which occur to do so, preliminary interviews with office building owners were held to gain more insight into this problem. This have led to practical information about this upcoming legislation and a brainstorm session about what possibilities there are to tackle this problem, or to create opportunities when investments would be made to meet the new legislation.

Literature study

The research has started with a proposal where the current situation, research problem, research goals, research question and research scope were defined. This has done followed by the book of Verschuren and Doorewaard (2015). The desk research of the proposal formed a foundation to the literature study of this research. This is supplemented which desk research which will help in answering to sub-questions and give input in the model. The current state of the Dutch office building stock (Sub-question 1), the definition of sustainability for office buildings in terms of people, planet and profit (Sub-question 2), opportunities in office building renovation (Sub-question 3) and research about the sustainability measures (Sub-question 4) have been answered with help of the literature study.

Design

This desk research is supplemented with further research about the theory of Barzilai (2010) and Binnekamp (2016) which is used in the model. This gives information about how to design a model which can help in the decision making. With this information, a prototype will be made first to test the working of this model. This model will be expanded afterwards in a final model which can be used for office buildings to help office building owners in making choices from several alternatives.

Expert meetings

Meetings are held with experts to provide practical insight and provide additional information which can't be found by desk research. Also, findings of the desk research will be compared with the knowledge of experts. This input will be used mainly to supplement the following information:

- Opportunities in development of sustainability office buildings (Sub-question 3).
- Sustainability measures and their effect (Sub-question 4).
- Composing sustainability measures packages (Sub-question 4)
- Weighting of criteria (Sub-question 5)

Case study

During the case study, the model will be tested within an office building. This office building will be an asset of the client (Jovi Investments BV) which will also provide the necessary project and building information. Also the building must meet various criteria. These criteria ensure that the model is tested as much as possible for what it serves as described in the problem description and goals definition. These office building criteria are as following:

- Existing office building (no new construction projects)
- No monument
- Minimum surface of 100 m²
- Energy label D or lower
- Intention of keeping the building until 2030 (towards energy label A)
- Detailed insight into building information

The case study will show whether the model works as it's intended for and which aspects need to be improved. This will be improved until it is a good working model for the case study. Conclusion and evaluation of the case study will lead to the final conclusion of the research and answer to the research question.

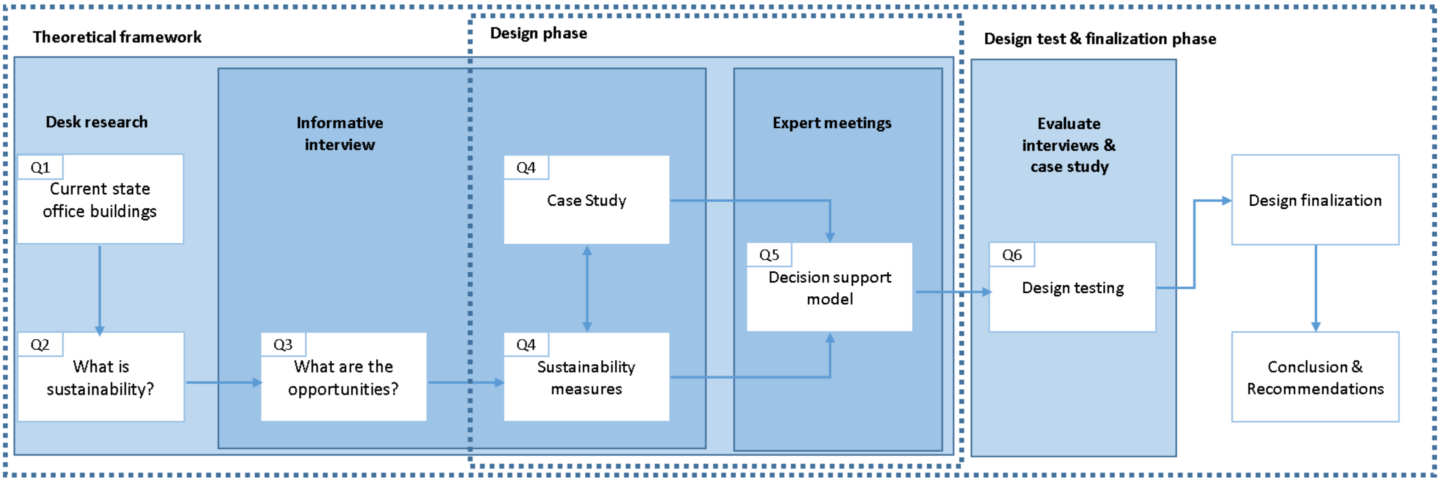

Figure 1 Research model

2. Current state of the building stock

This chapter describes the current state of the Dutch office building stock in order to answer sub-question 1 (What is the current state of the Dutch office building stock?) of the research.

2.1 Current situation

The EIB (Economisch Instituut voor de Bouw) and ECN (Energieonderzoek Centrum Nederland) has investigated the effects of the upcoming mandatory law. This law will regulate that the office buildings needs to have energy label C as minimum in 2023. Currently there are around 67.500 office buildings in the Netherlands. These buildings have a total of 85 million m² of floor space. The share of national monuments are around 3.3 million m², these national monuments do not have to meet the upcoming requirements of energy label C. To get an idea of the size of Dutch office buildings supply, some key figures are presented in table 2.

OFFICE BUILDINGS	
CURRENT SITUATION	
SUPPLY	85.000.000 m²
SHARE MONUMENT	3.300.000 m²
AMOUNT	67.500
ENERGY LABEL C OR HIGHER	11.625 (17%)
ENERGY LABEL D OR BELOW	20.303 (30%)
ESTIMATION	
ENERGY LABEL C OR HIGHER	47,4% of total supply
ENERGY LABEL D OR BELOW	52,6% of total supply

Table 2 Key figures office buildings (Arnoldussen, van Zwet, Koning, & Menkveld, 2016)

Almost 23% of the current supply of the total floor space has already have an energy label. The estimation of Arnoldussen et. All (2016), based on the year of construction and energy label database, is that almost 47,4% of the current office supply will already have an energy label of C or higher. Therefore this mandatory law affects 52,6% of the current office supply which has energy label of D or below.

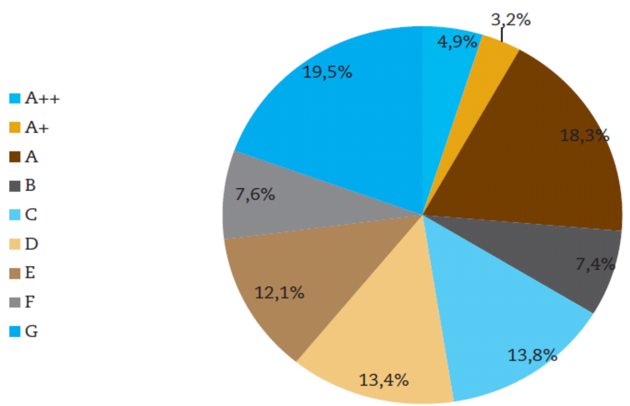

Figure 2 Distribution of office stock to energy label, 2014, excluding monuments (Arnoldussen, van Zwet, Koning, & Menkveld, 2016)

According to ECN (2017) the total use within the services sector in the Netherlands of gas is 181 PJ and electricity is 128 PJ. Office buildings contribute 20% on the total of gas and 19% on the usage of electricity while it only uses 18% of the total m² supply. Office buildings can contribute to the saving potential with the largest amount of 22%.

The current stock of office buildings will not only change because of the upcoming regulation but also change because of practical reasons. By natural course the current stock will improve in upcoming years in an autonomous way. Old buildings with a low energy label will be demolished when new buildings will be constructed with minimum energy label A. The stock with a G label decreases autonomously by almost 24%, between 2014 and 2030. At the same time, the stock with label A increases by 20%. Office buildings with characteristic features combined with a central location will not be quickly demolished and replaced. These buildings remain in use because of their attractiveness as an office building.

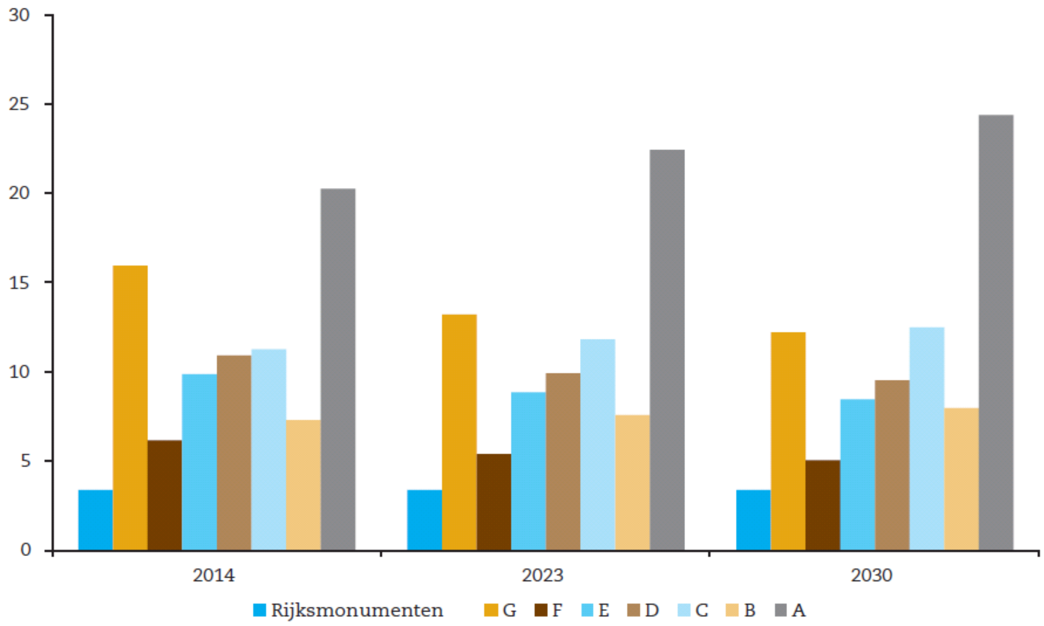

Figure 3 Autonomous development of office stock to energy labels, in m² (Arnoldussen, van Zwet, Koning, & Menkveld, 2016)

2.2 General building characteristics

ECN (2014) has mapped out the insulation values of an office building which is built during a particular year of construction and which technologies were available at that time and have been used for installations and lighting. Until 1974, buildings were built without any insulation. While up to 1920 the facades were without cavity. From that moment this changed to a cavity width of 100 mm and after 1965 with a cavity width of 200 mm. Also started from the year 1965, roof and wall insulation is used with Rc 1.3 and double glazed windows. From 1988, higher insulation values are built towards Rc 2.0. This changed in 1992 where insulation requirements apply in the building decree with a minimum of Rc 2.5. In 2012 the Building Decree tightened the Rc value from 2.5 to 3.5. From 2015, the insulation requirements in the building decree have been tightened to Rc 3.5 for the floor, Rc 4.5 for the facade and Rc 6.0 for the roof. Office buildings built before 1975 have a natural ventilation system, from 1975 mechanical extraction is customary. Only from 1992 onwards is a balanced ventilation system with heat recovery common to EPC requirements. Only buildings from after 1992 have a cooling installation. This results in general characteristics for office buildings with the different energy labels between F and C given in table 3.

Energy label	**G (19,5%)**	**F (7,6%)**	**E (12,1%)**	**D (13,4%)**	**C (13,8%)**
Year of construction	Van 1920 tot 1965	Van 1965 tot 1988	Van 1988 tot 1992	Van 1992 tot 1995	Van 1995 tot 2009
Most common location	Downtown	Business park	Main roads	Office district	Train station
Rc floor/facade/roof	0,15/0,36/0,39	*0,52/1,3/1,3*	*1,3/2.0/2.0*	*2,53*	*3,5*
Glazing windows	Single	*Double*	Double	Double	Double
Boiler	VR	*HR100*	HR100	HR100	HR107
Cooling	none	none	none	*Compression*	Compression
Ventilation	Natural	*Mechanical*	Mechanical	*Mechanical with heat recovery*	Mechanical with heat recovery
Light control	Departure switch	Departure switch	Departure switch	*Time switch*	Time switch

Table 3 Office buildings with different year of construction and their characteristics in terms of energy label (Arnoldussen, van Zwet, Koning, & Menkveld, 2016)

2.3 Conclusion

Office buildings have the largest energy saving potential within the service sector in the Netherlands. With upcoming mandatory law, estimation is that 52,6% of the office building supply needs to improve the energy label in order to meet this upcoming legislation. This development will not be fulfilled by natural course and measures need to be taken by office building owners. These measures differ per specific building and general characteristics of the different energy labels are given. These characteristics present a solid foundation for the development of sustainability measure packages which can be executed in order to improve the energy label to minimum C.

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3. Sustainability of office buildings

Sustainability is a term that is used in different ways. In each way the meaning of the word is different compared to another. According to Johnston, Everard, Santillo, & Robèrt (2007) around three hundred definitions of sustainability exist. For this reason, a clear definition of sustainability for office buildings and an explanation how this definition is related to the research problem and research goals needs to be given. This chapter is an answer to sub-question 2 (What does sustainability mean for office buildings?) of the research.

3.1 Definition of sustainability

Because sustainability is such a broad used term. The definition and reasoning which will be used in this research will be given. Sustainable development is the development that meets people's needs without compromising the ability of future generations to meet their own future needs . This protection of the environment is done with the impact that, in this research, the office building has on the environment. With this reasoning, sustainability can be seen as environmental sustainability which is defined by Morelli (2011):

"Meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them, …and more specifically, as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity. (Morelli, 2011)*"*

Morelli's (2011) definition focuses on the impact on the environment, which will be in the case of office buildings be caused by the energy performance, user behaviour, used materials and the re-use of materials. Sustainability can also be determined by the ability to withstand time, this refers to the determined life cycle period of the building and can be defined as resilience. This is also included in the definition of Morelli (2011). For example, the demand for office buildings can change, the amount of needed space could change or the number of employees per square meter or the way of working, like working at home. This asks for a certain degree of flexibility in office buildings, which can be defined as (part of) sustainability. But, this is not the focus of this research.

In this research we maintain the theory of John Elkington (1994). Elkington (1994) has developed the triple bottom line theory which is also known as the 3 P's or 3 dimensions: People, Planet, and Profit. He describes that sustainability is about the balance between these 3 dimensions (Kuhlman & Farrington, 2010). But what are these dimensions about in general?
The People dimension stand for the care of the people who are affected direct or indirect by certain actions. The Planet dimension stands for the contribution in solving environmental problems as also described by the definition of Morelli (2011). The Profit dimension stands about creating (economic) value and economic perspective of certain actions. In this research about sustainability of office buildings, these dimensions are framed and are explained in next section.

3.2 Triple bottom line theory

In the problem definition is made clear that three of the four key issues in this research are the effect of sustainability improvements on indoor environmental quality, energy efficiency and finance. These components can be classified as People, Planet and Profit (Elkington, 1994). In this paragraph the definition of the dimensions which will be handed in this research will be explained.

As stated before, the triple bottom line theory is about the balance between the 3 dimensions (Kuhlman & Farrington, 2010). It's impossible to define a general optimum for the balance for all organizations between the 3 dimensions. This optimum will be different for each organization and the ratio between these elements is their optimal balance. But an organization must keep in mind that when there is too much focus on one dimension, another dimension might suffer because of it. The definition of these lines will vary from client to client. Martin (2012) visualized this relation after the United Nations General Assembly adopted these relations by the General Assembly on 15 September 2005. It is commonly agreed what is important as in: "Important in understanding the concept of sustainable development is the connection between environmental, economic and social components. Each component acts on the other whose impacts are emitted" (Teodorescu, 2012).

Figure 4 Dimensions of Sustainability (Martin, 2012)

In this research, the definitions which will be handed about these dimensions needs to be stated. In terms of People, care for the people affected direct or indirect are the employees within the office building. These employees are affected directly because the sustainability improvements have an effect on the indoor environmental quality (IEQ) of the office building. Further in this research will be described what effect the indoor environmental quality has on the employees and why this is important.

The Planet dimension aims at energy usage improvement of office buildings. Office buildings can contribute to the saving potential with the largest amount of 22% in the service sector (Sipma, 2014). Office buildings have a significant influence on the total energy demand. Lower demand reduces the need to generate energy and security of current supply.

Profit is affecting most actions of organizations, while the profitability of sustainable measures is questionable or financing these measures is not taken into account. Therefore the sustainability measures needs to be financially attractive and create more practical value, more income or return on investment.

3.3 Energy performance

To improve the energy performance of an office building, which affects the Planet dimension, basic knowledge will be provided on how this can be done. "Costs savings, security of supply and environment are the main reasons to improve energy performance. Next to these considerations it must be noticed that energy in itself is not an environmental problem but the cause of several environmental impacts" (Itard, 2012).

Improving the energy performance reduces the energy costs of an office building and therefore also the operation costs. The financial benefits are, for office buildings, in advantage of the tenant because in most case they have a separate energy bill. When the tenant rents with an all-in rent price (including service and energy costs), financial benefits are an attractive reason for applying energy efficiency measures. The payback period of investments differs but a short payback period is more attractive. When there is a shorter payback period, the financial benefits will appear earlier in the balance sheet.

Second reason to improve energy performance is security of the current supply. By reducing our energy demand we consume less quickly the abiotic and biotic resources. Itard (2012) believes in her Three Steps Strategy that this is necessary because "reducing the energy demand mainly because it seems easier to achieve than a change in energy conversion systems from fossil fuels to renewable resources" (Itard, 2012). This energy demand is a cause for environmental impacts which is the third reason. "By emitting combustion products into the atmosphere, the production of energy contributes to the depletion of ozone layer, global warming, acidification, eutrophication, photochemical oxidation (smog), eco toxicity (soil and water) and humane toxicity" (Itard, 2012). By reducing the energy demand, the impact on the environment will be reduced.

The energy demand is dependent on the building characteristics, users & appliances and the outdoor temperature. To reduce the energy demand changes could be made in the building characteristics and users behaviour. Building characteristics such as the size, orientation, type of façade, walls, roofs, windows glazing, insulation, materials, and installations influence the energy demand. Users determine the energy demand with their behaviour, quantities, time spent in the building and preferences (Itard, 2012).

3.4 Energy index

The purpose of the energy label is to provide insight into the energetic quality of one building compared to similar buildings and providing insight into the potential of possible energy-saving measures to improve the energy quality of the building. Buildings of the same type can be compared in terms of their energy use.

The energy index is calculated by dividing the total building-related primary energy use by the permissible primary energy use that is allocated to the building on the basis of the use function, use area, loss surface, ventilation and the presence of cooling. The total building-related primary energy consumption comprises the primary energy consumption for heating, fans, lighting, pumps, cooling, humidification and hot tap water; energy that is generated in the building with solar panels or heat-power coupling is removed from this. The determination method for the energy label for utility buildings is described in ISSO publications 75.1 to 75.3 (Sipma, Kremer, & Vroom, 2017).

Figure 5 Energy label with corresponding energy index values (RVO.nl, 2018)

3.5 Indoor environmental quality

Building characteristics have effect on the indoor environmental quality (IEQ) while the IEQ affect the users of the office building. Several studies has shown that the time spent indoors (on average 90%) dominate compared to outdoor (10%) in developed countries. Bruinen De Bruin et al. (2004) has conducted a study in Milan which is comparable to the lifestyle in the Netherlands. Most of the time spent indoor are at home (55,7%) and at work (30%). In 2015 the amount of office jobs were 1.852.473 which was 23,9% of the total jobs in the Netherlands (Buitelaar, van den Berge, van Dongen, Weterings, & van Maarseveen, 2017). Employees spend approximately 20 to 60h per week at the office (Wargocki, 2011). Problems with the IEQ thus have a high impact on human well-being. Moreover, pollutant concentrations are often higher inside buildings than outside them. Approximately 90% of the business operating costs consists of staff costs in salaries and benefits (World Green Building Council, 2014). The yearly absenteeism of employees in the Netherlands is around 3.3 million employees, which is 47% of the total employees and 4% of all working days, costs employers 11.5 billion euro per year, 4% of the total labour costs (Dutch Green Building Council, 2015).Therefore, it is important that the IEQ needs to be in good condition.

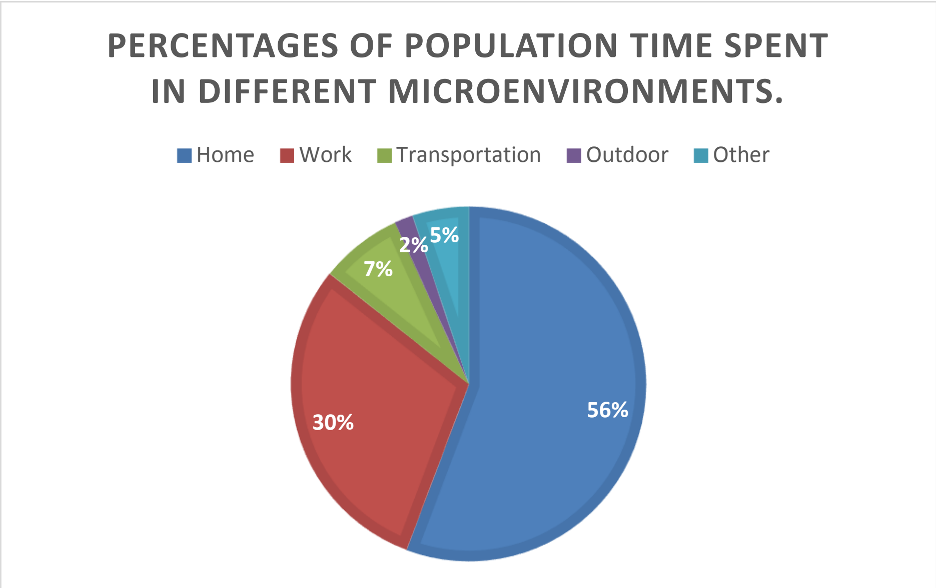

Figure 6 Percentages of population time spent in different microenvironments (Bruinen De Bruin, et al., 2004)

A study has also shown that in only 11% of the buildings surveyed, 80% or more of the users are satisfied with their buildings thermal comfort. Air quality scores higher, with 26% of buildings having 80% or occupant satisfaction (Huizenga, Abbaszadeh, Zagreus, & Arens, 2006)

3.6 What affects the indoor environmental quality?

Effect on the indoor environmental quality come from both indoor and outdoor. The indoor environment is affected by 5 categories: chemical pollutants, biological pollutants, thermal comfort, noise and lighting (Meijer, 2012). The health effects of these categories are given by Meijer (2012) and shown in table 4.The effects of pollutants are more serious but people experience more annoyance from the other categories. Sources of outdoor pollutants are emissions of activities outside. In this section the indoor sources will be elaborated because these affect the indoor environment quality directly.

Health effect	Chemical or biological pollutants	Thermal comfort, noise or lighting
Stopped-up or running nose	✓	✓
Wheezing breathing	✓	
Tightness of the chest	✓	
Shortness of breath	✓	
Hay fever	✓	
Sore throat	✓	✓
Tired or running eyes	✓	✓
Irritation of contact lenses	✓	
Headache	✓	
Extreme fatigue	✓	
Concentration problems	✓	✓
Repeatedly waking up during night	✓	✓
Dry or irritated skin	✓	
Muscular pains	✓	
Heart attacks		✓

Table 4 Health effects as a result of exposure to pollutants and poor thermal comfort, noise or lighting (Meijer, 2012)

Chemical pollutants

There are four type of sources of chemical pollutants (Meijer, 2012): "Building materials, soil, consumer products and combustion gases". Building materials such as paints, glues and plastics emit volatile organic compounds. The emission rates are high after application and decreases slowly during its lifetime, while the life cycle profile including production is better than low emission materials. Stony materials such as concrete and bricks emit radon which is a gas that doesn't undergo chemical reactions and penetrates to the indoor air which can cause lung problems when it's inhaled. Because the soil is manly from sand or clay in the Netherlands, the radon emission rates can be disregarded. Consumer products such as furniture, cleaning agents and electronic equipment also emit volatile organic compounds but is regarded as user behaviour and difficult to monitor. Combustion gases are formed when preparing a meal on a stove or heating water in a gas heater. When the combustion is not complete, toxic gases can be formed which may have direct effects on mental performance (Wargocki, 2011).

Biological pollutants

There are five types of sources of biological pollutants (Meijer, 2012): "Moulds, mites, plant and pet allergens, legionella and people" which are emissions from living organisms. Moulds and mites are generally found in areas where there is water and condensation takes place in the area. People can have plant and pet allergens which may cause symptoms of distress that reduce performance (Wargocki, 2011). Legionella is a bacteria that lives in water. To prevent this you will have to keep the water temperature in boilers and pipes above 60°C and flush the warm water system after it has not been used for a long period. The final source are as stated before the people. Bad smells and moisture emissions are the main emissions of a person. Bad smells cause distress and reduces motivation (Wargocki, 2011).

Thermal comfort, noise and lighting
Other 3 sources which affect the indoor environment are thermal comfort, noise and lighting. Meijer (2012) believes that the thermal comfort us determined by parameters as the indoor temperature, the surface temperature of walls, ceilings and floors, air movements, humidity, the type of activity and the type of clothes worn. Some of these parameters are interrelated such as the acceptable air temperature depends on the surface temperature of the walls, the acceptable air velocity while humidity depends on the indoor temperature. Noise in the building results in annoyance. The main causes are outside sources, indoor sources and sources from neighbours. Noise problems are often related to problems with air quality because of the noise the ventilation system or outside sources produce. Lighting have three sources of problems such as glare and too little (day)light which can cause psychological problems (Meijer, 2012). Exposure to daylight reduces these problems and also influence the energy consumption, because less artificial light is needed and when the windows are facing the sun the need of heating will be less. During the summer, this can be a cause for overheating but windows blinds can solve this problem. The need of daylight is contradicting on the insulation level of the building, because windows have generally a lower insulation level than the façade construction. The colour of the lighting in a room also determines the thermal comfort level. For example the first LED light bulbs were perceives as giving uncomfortable white light were the newer types are improved.

In this research, the aspects regarding indoor environmental quality are the aspects described above: Thermal comfort, noise and lighting.

Impacts of the indoor environmental quality on health, performance and productivity.
Indoor environmental quality plays an important role for health, performance and productivity (Wargocki, 2011). Several studies have shown that it is hard to translate this into economic calculations. But these studies have shown that there are significant effects of the IEQ on health, performance and productivity. There are discussions about the definition of the terms of performance and productivity. Therefore it is important which definition is used in this research.

Performance can be defined as "the ability of an employee to accomplish his mission based on the expectations of an organisation" (Perrin, 2016). When translating this into the field of offices, this can be related on the suitability of the indoor environmental quality to deliver qualitative work by the employee. The economist/engineer definition of productivity is determined as "an efficiency measure: the ratio of outputs over inputs", where both usually are expressed in dollar terms (Pritchard, 1995). But this depends on the work that the employee is carrying out.

After analysing several studies, Seppänen and Fisk (2006) conclude that "many measures to improve indoor air environment are cost-effective when the health and productivity benefits resulting from an improved indoor climate are included into the calculations" (Seppänen & Fisk, 2006). The use of such models, where health and productivity benefits are included into the calculations, would be expected to lead to improved indoor environments, health and productivity (Seppänen & Fisk, 2006). Several studies have been conducted in this area and some of them also tried to draw quantitative conclusions what effect some factors will have.

Health
Several researchers have written about the impact of the indoor building environment on health. Improving the outdoor air supply rate will reduce illness and sick leave prevalence. Wargocki (2011) states that doubling the outdoor air supply rate can reduce illness and sick leave prevalence by roughly 10%. This is less than what Seppänen and Fisk (2006) suggest with their concentration model where one can estimate that "doubling the average ventilation rate from ventilation rate of 12 L/s to 24 L/s per person would decrease the sick leave prevalence in an office from 2% (5 days per year) to 1.5% (3.8 days per year)".
Having (day)light in the workspace also affects the health of the employee. A recent study by neuroscientists suggested that office workers with windows received 173 percent more white light exposure during work hours, and slept an average of 46 minutes more per night (World Green Building Council, 2014). While a study

in view quality, daylighting and sick leave of employees explained 6.5% of the variation in sick leave (World Green Building Council, 2014). LED lighting gives better and constant light, discolours ten times less quickly than TL, and there are no glass splinters and mercury vapours released at breakage. LED has no stroboscopic effects (flickering or blinking effects), no high voltage peaks and magnetic fields, and no harmful UV radiation (Energeniaal, 2018).
Temperature of the workplace does also affect the SBS-symptoms. “Studies indicate a 12% increase in the intensity of SBS-symptoms per 1 °C increase temperature above 22.5 °C” (Seppänen & Fisk, 2006). While a constant low temperature of the workspace will eventually ensures your body that you cannot offer resistance to get a cold. Also a high difference between the temperature outdoor and indoor can cause your body to get shocked, especially when you move from the warm indoor climate to a cold temperature.
Noise levels can become more serious than you will think. High background noise has a direct link with a higher adrenaline level of the employee. A chronical high adrenaline level increases the risk for heart disease. In addition, there is a direct relationship between the noise level of open office environments and suffering of cramp by the employees. This is done subconscious to avoid the noise level and may result in RSI complaints in the long term. In particular, uncontrollability noise causes stress and reduces task motivation (Dutch Green Building Council, 2015).

Performance
Several researchers have written about the impact of the indoor building environment on work performance of employees.
Perceived air quality is important in this case. Wargocki (2011) states that “every 10% increase in the percentage satisfied with the air quality can increase the performance of office work by roughly 1%, implying that the performance of office work may increase even by 5% when the air quality is improved from a mediocre level often found in practice” (Wargocki, 2011). This is comparable to the results of Bako-Biro (2004) where the results imply that every 10% increase in the percentage satisfied with the perceived air quality the performance of text typing can be improved by 0.8%. This is also confirmed by the study of Seppänen and Fisk (2006) where improving the ventilation rate improves the performance in relation to the reference value. But a decrease in indoor air quality may change attitudes about the employer, reduce motivation, and cause distraction, which eventually affects work performance of the employee. This happens through complaints and internal communications between employees. (Wargocki, 2011).
Different light also affects the performance of the employee. Michigan State University performed a research last year that concludes exposure to dim light will let you lose 30% of capacity in the hippocampus, which is critical brain region for learning and memory. This is not permanent and will restore within 1 month, but most employees don’t have 30 days off to get fully recovered (Henion, 2018).
The effect of the temperature on performance is defined by Seppänen and Fisk (2006). They reanalysed 150 assessments of performance from 26 studies and concluded that the maximum performance of an employee is at 21.6 °C and that this will reduce when it gets colder (4%) or warmer (6%) (World Green Building Council, 2014).
Noise levels also affect the performance. A study in 1998 found that there was up to a 66% drop in performance for a ‘memory for prose’ task when exposed to different types of background noise. While a follow-up study by the same authors in 2005 found that 99% of people reported that their concentration was impaired by office noise. (World Green Building Council, 2014). While multitasking at a complex task it takes on average 25 minutes to start again and 8 minutes to get on the same level of concentration (Dutch Green Building Council, 2015).
Also a reduction of the prevalence of weekly central nervous symptoms by 7.4% would lead to a 1.1% increase in performance, whereas a reduction of intensity of such symptoms by 10% would lead to a 5% increase in performance (Niemela, Seppänen, & Reijula, 2003) (Wargocki, 2011).

Productivity

Several researchers have written about the impact of the indoor building environment on the productivity of employees. Wargocki (2011) states that "doubling the outdoor air supply rate can increase office work by roughly 1.5%". Research in 2003 identified 15 studies linking improved ventilation with up to 11% gains in productivity, while a meta-analysis in 2006 of 24 studies found that bad air quality can lead till up to 10% decrease of productivity (World Green Building Council, 2014).

A 1% increase in productivity corresponds to decreased sick leave of 2 days per year, decreased breaks from work, increased effective time at work of 5 min per day, or 1% increase in the effectiveness of physical and mental work.

"A minor 1% increase in office work can offset the annual costs of ventilating the building, that the full costs of installation and running of the buildings can be offset by productivity gains just under 10%, and that the payback time for investments to reduce indoor air pollution is generally less than 2 years" (Wargocki, 2011).

"Self-estimated productivity seems to be affected when there are more than two SBS symptoms per person in a building" (Wargocki, 2011).

Indoor effect	Aspect	Results	Source
Air quality	Health	Doubling outdoor air supply can lead to: - Reduce illness and sick leave prevalence by 10% - Sick leave prevalence from 5 days to 3.8 days per year	(Wargocki, 2011) (Seppänen & Fisk, 2006)
Air quality	Productivity	Doubling outdoor air supply can lead to: - Increased office work by 1.5%	(Wargocki, 2011)
Air quality	Productivity	Air quality can lead to: - 11% gains in productivity - Decrease of the productivity till 10%	(World Green Building Council, 2014)
Air quality	Performance	Every 10% increase in the percentage satisfied with the air quality: - Increase the performance by 1% - May increase even by 5% from a mediocre level - Increase the performance by 0.8%	(Wargocki, 2011) (Bako-Biro, 2004)
Air quality	Productivity	1% increase in productivity: - Offset the annual costs of ventilating the building	(Wargocki, 2011)
Temperature	Health	Increase of 1°C above 22.5 °C can lead to: - 12% increase in the intensity of SBS-symptoms	(Seppänen & Fisk, 2006)
Temperature	Performance	Maximum performance at 21.6 °C. - 4% reduction in performances at cooler temperatures - 6% reduction in performances at warmer temperatures	(Seppänen & Fisk, 2006) (World Green Building Council, 2014)
Lighting	Health	Office workers with windows: - Receive 173% more white light exposure - Sleep 46 minutes more per night	(World Green Building Council, 2014)
Lighting	Health	Office workers with windows: - Receive 173% more white light exposure - Sleep 46 minutes more per night	(World Green Building Council, 2014)
Lighting	Performance	Exposure to dim light will lead to: - Lose 30% of capacity in a critical brain region temporary	(Henion, 2018)
Noise	Performance	Background office noise can lead to: - 66% drop in performance for a 'memory for prose' task - Take 25 minutes to start again after interruption - Take 8 minutes to get on same concentration level after interruption	(World Green Building Council, 2014) (Dutch Green Building Council, 2015)
	Performance	Reduction of central nervous symptoms: - By 7.4% would increase performance by 1.1% - By 10% would increase performance by 5%	(Niemela, Seppänen, & Reijula, 2003) (Wargocki, 2011)

Table 5 Key figures impacts of the indoor environmental quality on health, performance and productivity

3.7 Conclusion

Sustainable development is the development that meets people's needs without compromising the ability of future generations to meet their own future needs . This protection of the environment is done with the impact that the office building has on the environment. With this reasoning, sustainability can be defined as environmental sustainability as defined by Morelli (2011). This research maintains the definition of sustainability by John Elkington (1994), who developed the triple bottom line theory. The People dimension refers to the indoor environmental quality and the impact this has on the users of the building which are for the most part employees. The Planet dimension stands for the energy use of the office building. And the Profit dimension is about creating economic value with the sustainability measures. Also, the impact that the IEQ has in terms of health, productivity and performance is elaborated which can be seen as opportunities and threats.

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4. Opportunities in office building renovation

An office building renovation brings several opportunities with them. We can divide these opportunities into technical, financial and organizational opportunities. Also within these opportunities the effect of sustainability measures, and thus an improved energy label, will be given on behalf of the balance of People, Planet & Profit. This chapter gives answer to sub-question 3 (What are the (subsidy) opportunities in office building renovation and what does an improved energy label mean in terms of People, Planet & Profit?) of the research.

4.1 Financial opportunities

Sustainability measures bring financial opportunities (Profit dimension) with them. These opportunities are for both the building owner as the tenant. The different financial opportunities can be summarized as increase in rent price and market value, lower energy costs, financing and subsidy arrangement and will be elaborated below:

Increase in rent price and market value

Office buildings with energy label C or higher will yield more income. A statistical analyse from Cox (2017) has shown that the difference in rent between sustainable office buildings and non-sustainable office buildings is 16% (Cox, 2017). Office buildings with minimum energy label A, yield 18,9% more rent compared to non-sustainable office buildings. Office buildings with an energy label B or C has shown an increase of 12,8% compared to non-sustainable offices. Also ING Real Estate Finance and the University of Maastricht has conducted a study in 2017 about the market value and rent as like others authors about the Dutch office market. The different outcomes are given in table 6. Sustainable office buildings increase in their market value. ING Real Estate Finance and the University of Maastricht (2017) state that this was 9,1% in 2015 and 8,6% in 2016. And according to a McGraw Hill Construction study, building green leads to an increase in building values which is 6.8% for existing building projects (O'Mara & Bates, 2012). Thereby we can conclude that improving the energy label of an office building will lead to increase in the rent price and market value.

Author	Premium rent value
Heineke (2009)	3,7 %
Berkhout (2010)	5 %
Broek (2010)	12 %
Kok & Jennen (2012)	7 %
Baas (2013)	10,7 %
ING Real Estate Finance & University of Maastricht (2017)	11,8% (2015) 9,9 % (2016)
Cox (2017)	16 %

Table 6 Change in rent price after sustainability measures

Lower energy costs

Sustainability measures which will upgrade the energy label will result likely to savings in gas and electricity. This reduced usage will lead to lower energy costs. Theoretical savings of gas and electricity usage are given in table 7 with the resulted cost savings per m² per year (Arnoldussen, van Zwet, Koning, & Menkveld, 2016).

To C from		**G**	**F**	**E**	**D**	**C**	**B**
Gas savings	m³ per m² per year	18	-1	-1	-1		
Electricity savings	kWh per m² per year	19	29	28	14		
Cost savings	€ per m² per year	13	3	3	1		
To B from		**G**	**F**	**E**	**D**	**C**	**B**
Gas savings	m³ per m² per year	17	2	-1	-1	0	
Electricity savings	kWh per m² per year	30	30	31	26	8	
Cost savings	€ per m² per year	14	5	3	2	1	
To A from		**G**	**F**	**E**	**D**	**C**	**B**
Gas savings	m³ per m² per year	17	2	2	-1	0	0
Electricity savings	kWh per m² per year	31	40	29	41	12	4
Cost savings	€ per m² per year	14	6	5	4	1	0,5

Table 7 Theoretical savings of gas and electricity usage (Arnoldussen, van Zwet, Koning, & Menkveld, 2016)

The building owner who invests in sustainability measures or energy-saving measures usually doesn't benefit directly from the investment. This is because the direct profit, a lower energy bill, ends up entirely with the tenant. For the building owner, the advantage lies in the fact that the satisfaction of the tenant rises so he can adjust the rent or bind for a longer time. Another possible outcome is that the building owner will opt for an All-in rent price, this is one of the so-called Triple-win models that are considered promising in the European project guarantEE to solve the split incentive and to speed up energy saving in buildings (Simons, 2017). Here the building owner can ask for an all-in price including rent and energy costs, so eventually when he takes energy-saving measures the benefit will be in advantage of the building owner.

Financing

Building owners finance most of their portfolio by getting financing by the bank. To get financing when buying an office building is nowadays only possible when the building is a sustainable building unless a sustainability plan has been drawn up by the building owners. Important Dutch banks such as ING (2016) and ABN Amro (2016) have spoken this out. Even when the existing financing needs to be extended, Dutch banks set the requirement that the building already needs to have energy label C. When this is not the case, loans will not be extended which can cause many problems for the building owner. There are possibilities to acquire the financing of the investment for making the building more sustainable in total by the bank (ABN AMRO, 2016). When this upgrade/replacement is done at the moment that the calculated maintenance needs to take place, the costs of it can feel less than it actually is. This will be because a percentage of the costs would also be made to maintain the current situation without any sustainability improvement.

Subsidy

After financing the sustainability measures there are also several financial arrangements available. The Dutch government supports taking energy-saving measures, including several subsidies as EIA, ISDE, SDE+, MIA and Vamil. These subsidies will meet a certain part of the investment. Below these subsidies will be explained.

Energie-investeringsaftrek (EIA): The energy investment tax deduction (Energie-investeringsaftrek) is applicable when investments are made in energy-efficient techniques and sustainable energy. 54,5% of the investments costs can be deducted from the taxable profit on top of the usual yearly depreciation. Specific investments are formulated on the energy lists which qualify for this subsidy. If you want to make an investment that also saves energy but is not specifically described on the energy List it must meet a number of requirements.

Investeringssubsidie duurzame energie (ISDE): The investment subsidy renewable energy (Investeringssubsidie duurzame energie) gives an allowance for the purchase of solar water heaters, heat pumps, biomass boilers and pellet stoves. The assets must meet certain terms and conditions.

Stimulering Duurzame Energieproductie (SDE+): When you start producing renewable energy, you might be eligible for the Sustainable Energy Production Promotion (Stimulering Duurzame Energieproductie) incentive. There are 6 categories: Biomass, Geothermics, Water, Wind and Sun. To be eligible for this incentive you must meet certain terms and conditions.

Milieu-investeringsaftrek (MIA) and Willekeurige afschrijving milieu-investeringen (Vamil): MIA and Vamil are subsidies for environmentally friendly business for entrepreneurs. The environmental investment allowance (MIA) offers you the opportunity to reduce the taxable profit. You can deduct up to 36 percent of the investment amount from the taxable profit. The percentage of the deduction depends on the environmental effects, type of installation and the prevalence of the asset. With the Random depreciation of environmental investments (VAMIL) you can write off an investment at any time. For investments from 2011 random depreciation is limited to 75%. By faster depreciation you reduce the taxable profit and you pay less tax in that year. This offers you an interest rate and liquidity benefit. When a certain regulation is used for an investment. This investment can't be used for another regulation.

Effect on Profit

There are several effects of improving the energy label when you look at it from the Profit dimension. As it can be seen from the opportunities perspective, the rent price and asset value will increase with when the building will improve to an energy label of C or higher. Also the energy costs will decrease from 1 till 13 € per m² per year while the costs to improve the energy label will vary from 9 till 57 € per m² (Arnoldussen, van Zwet, Koning, & Menkveld, 2016). The payback period is between 3 to 6,5 years when the energy saving will become a direct benefit of the building owner by charging an all-in rent price. Most investments qualify also for financial arrangements like tax deduction.

4.2 Technical opportunities

Sustainability measures bring also technical opportunities (Planet dimension) with them. These opportunities are not dependent on the exact measure. Measure-bound opportunities are left out of consideration. The different technical opportunities will be elaborated below:

Savings in gas and electricity usage

When analysing table 7 of Arnoldussen et all. (2016) the most important technical opportunities are the gas and electricity savings which can be realized and is what matters and the intended result of the new legislation. These savings can be up to 18 m^3 gas and 29 kWh electricity per m^2 office space per year.

Lifetime extension

Sustainability measures will extend the lifetime of an office building compared to the situation that these measures will not have been taken and the office building will not meet the energy label C restrictions (Kok & Jennen, 2012). Lifetime extension also leads to the usage of less energy resources on the long term when the building provides good energy performance.

Perspective towards energy label A

Measures can be taken with a perspective of realize energy label A in 2030. So these taken measures must be compatible with the realization in the future. When handling this correctly the measures taken for realizing energy label C will contribute in realizing energy label A and will not form an obstruction.

Modern technique

Sustainability measures are innovative measures which are developed in the years thereafter. These developments are furthermost likely technically improved and will look modern. This look is also a financial opportunity. These new techniques have several added values for the user as in energy savings tools, insight in energy consumption, control over the climate in workplace, which also affect the organizational opportunities (van Miert, Verburgt, & de Ruiter, 2012).

Effect on Planet

The effect of improving the energy label regarding the Planet dimension is that you can save up the energy usage. The savings can be up to 18 m^3 gas and 29 kWh electricity per m^2 office space per year (Arnoldussen, van Zwet, Koning, & Menkveld, 2016).

4.3 Organizational opportunities

Sustainability measures bring also organizational opportunities (People dimension) with them. These opportunities are for both building owner and the organization who is renting the building. The different organizational opportunities will be elaborated below:

More control

Sustainable measures can have more control panels so that the indoor environment can be controlled separately on each room/workplace.

Strengthen competitive position

If it succeeds to save costs, sustainability measures can certainly also influence the competitive position and thus the survival of the organization or company (van Miert, Verburgt, & de Ruiter, 2012).A brand building plays a major role in the positioning of a brand. Such a building functions as an icon for organizations. It shows which values are crucial for the user. In order for the existing brand building to continue to play this role, it is necessary to renovate the building. The adjustment will mainly have to do with the identity of the organization, which directly influences the competitive position (van Miert, Verburgt, & de Ruiter, 2012).

Attract tenants and their employees

Improving the energy label can attract tenants (O'Mara & Bates, 2012). This will also affect the finance. Also a healthy building will help the organization in attracting employees in a difficult labour market.

Better work environment

Improvement in the energy label can have a positive influence on the employees. This can affect their health, work performance and/or productivity as described is previous sub-question.

Effect on People

The effect of improving the energy label regarding the People dimension is that the sustainability measures can help improving the indoor environmental quality. Improvement of the indoor environmental quality can have positive influences on the health, performance and/or productivity of the employees as described in previous sub question.

4.4 Conclusion

The opportunities can be divided into technical, financial and organizational opportunities. Savings in up to 18 m^3 gas and 29 kWh electricity usage per m^2, lifetime extension, perspective towards energy label A and modern technique are technical opportunities. Increase in rent price and market value, lower energy costs from 1 till 13 € per m^2 per year, financing and subsidy are the financial opportunities. More control, strengthen competitive position, attract tenants and their employees and a better work environment are organizational opportunities.

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5. Sustainability measures

Several measures can be performed to improve the energy efficiency. In order to gain a most comprehensive list of these measures, desk research will be performed with measures which can be applied. Additionally, renovation projects will be considered to see if there are other measures taken which are not founded during desk research. Concluding, there are interviews held with experts in their field to fill the gaps in the list and gain further insight about the measures. This chapter gives answer to sub-question 4 (What generic (combination of) technical sustainability measures can improve the sustainability and what effect will it have in terms of People, Planet & Profit?) of the research.

The starting point of the sustainability measures are the measures which are given in the tool Energiebesparingsverkenner (energy saving explorer) of RVO (2017). The categories for building measures are divided as explained earlier in categories. These are Insulation façade, Insulation floor, Insulation roof, Glazing windows and blinds, Heating, Cooling, Ventilation and Lighting. This will be supplemented with recognized measures of the government as described in Activiteitenregeling milieubeheer applicable from 01-01-2018 until 04-04-2018. Energy generation methods are left out of consideration because they have no influence on the indoor environmental quality. Below each category will be elaborated on with the way of working of the measures.

5.1 Insulation façade, floor and roof

In winter, a building loses heat through the so-called shell. The shell is the partition between indoor and outdoor, which consists of the (ground) floor, the facades (including windows and doors) and a roof. A building also loses heat because it is ventilated. How, where and how much heat you lose, varies per property. It depends on: orientation, size, type, (not) isolated and ventilation system. The better the building is isolated, the less heat it loses in the winter, which means less heating in the winter, which saves energy and money (Ubbels, 2017). In summer a better insulation ensures that heat is keep inside, which requires cooling to lower the temperature.

There are several ways to improve the insulation in existing buildings, where each measure also has different levels of thermal resistance. In order to understand the thermal resistance principle, some key formulas are elaborated which are correlated with each other.

The U-value expresses the amount of heat that is passed per second, per m² and per degree of temperature difference between one side and the other side of a wall (construction). The U-value is also called the heat transfer coefficient. The value indicates the degree of heat conduction of a wall: a high U-value means a thermally poorly insulating wall, a low U-value means a thermally well insulating wall. The unit for the U-value is W/(m²·K). The heat flow through a wall can be calculated with:

$$Q_w = U \times A \times \Delta T$$

Q_w = the heat flow (heat loss) in watts
U = heat transfer coefficient in W/(m²·K)
A = the surface of the wall in m²
ΔT = the difference between the temperature on one side and the other side of the wall in degrees Celsius or Kelvin.

Another way to express is by doing it reversed. This is called the heat resistance and is expressed as R_{res}. The formula to reverse this is as follow:

$$R_{res} = 1/U$$

Therein is R_{res} (in m²·K/W), the heat resistance of a wall per square meter and per degree temperature difference.

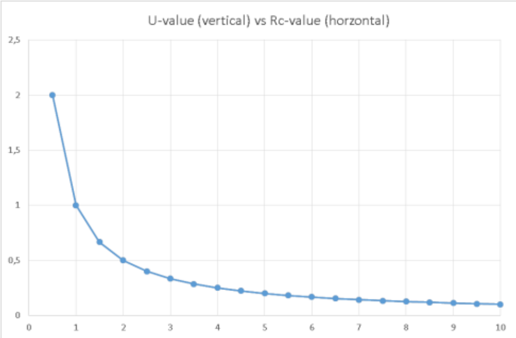

Figure 7 Rc-value vs. U-value (x10) (van Rooy, 2014)

The heat flow through a wall (expressed in watts) at a certain temperature difference between both sides of the wall is calculated as:

$$Q_w = (T_a - T_b) \times A / R_{res}$$

Q_w = the heat flow (heat loss) in watts

T_a and T_b = the temperature on both sides of the wall in degrees Celsius or Kelvin

R_{res} = the heat resistance of the wall in m²·K/W

A =the surface of the area of wall where the heat flow is calculated in m²

The total heat loss through a wall can then be calculated by taking the total area of the wall in m² in the above calculation for A.

The heat transfer coefficient of a simple wall can be determined by adding the heat resistance of the layers of which a wall is built up and determining the inverse value. In more complicated situations (for example, combination of window and frame) the thermal resistance must be calculated using the finite element method.

Calculation of the heat resistance R_{res}, with which the U-value is determined:

$$R_{res} = R_i + R_1 + R_2 ...+ R_n + R_o$$

R_{res} = the calculated thermal resistance of the wall (the total construction)
R_i = the heat resistance of the air layer on one side of the wall
R_o = the heat resistance of the air layer on the other side of the wall
R_1 to R_n = the thermal resistances of the layers from which the wall is composed.

On each side of the wall there is a thin layer of air, in which a complicated movement takes place. The thickness and therefore the heat resistance of this layer of air depend on the circumstances. The value 0,04 $m^2 \cdot K/W$ is used as the calculation value for the outside of a wall and a value of 0.13 $m^2 \cdot K/W$ for the inside of a wall.

Heat resistance of a layer
The thermal resistance of a layer of material depends on the thermal conductivity and the thickness of the layer. The thermal resistance of a layer is determined by:

$$R = d / \lambda$$

R = the heat resistance in $m^2 \cdot K/W$
d = the thickness of the layer in m
λ = the thermal conductivity in W/(m·K) of the material of the layer.

The thermal conductivity of a material can be looked up in tables with the properties of various materials. Sometimes the old designation kcal / (m·h·C) is still used in these tables. This is easy to calculate with:

$$\lambda \text{ in kcal / (m·h·C)} \times (4{,}19 / 3{,}6) = \lambda \text{ in W/(m·K)}$$

The different levels of thermal resistance of the façade which are common in office buildings is between 0 and 1.3, 2, 3.5 and 5 m²·K/W. This thermal resistance is the sum of all materials in the façade from inside till outside. Because of the infinite ways that this can be realized a common façade construction is taken to calculate the thermal resistance value. This façade construction is as following (started from the outside):

- Masonry 100mm (a)
- Cavity 40mm (b)
- Isolation 80mm (c)
- Sand-lime brick 100mm (d)

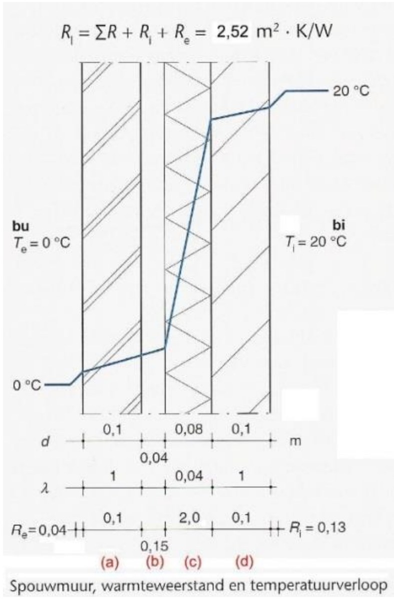

Figure 8 Thermal resistance value (Maessen & Wolfs, 2004)

Each level has another impact on the 3 dimensions. The exact impact is different in each building situation. But we already know on what it will have an impact and if this will be positive/negative. Also the generic costs of the measure will be given which will be basic starting point of the investment costs in final model. Deviations (for example project specific) will be corrected after expert interviews in the final model.

Measure	Costs		Unit	Effect on IEQ				Effect on People		
	Separate intervention	During renovation		Air quality	Thermal comfort	Noise	Lighting	Health	Performance	Productivity
Exterior wall insulation			€/m² NGO							
Rc = 1.3	158	135								
Rc = 2.0	152	129			X	X		X	X	X
Rc = 3.5	156	133								
Rc = 5.0	161	137								
Cavity insulation			€/m² NGO							
Rc = 1.3	23	16								
Rc = 2.0	20	13			X	X		X	X	X
Rc = 3.5	21	14								
Rc = 5.0	24	17								
Interior wall insulation			€/m² NGO							
Rc = 1.3	109	98								
Rc = 2.0	105	94			X	X		X	X	X
Rc = 3.5	107	96								
Rc = 5.0	111	100								
Roof insulation (on existing cover)			€/m² NDO							
Rc = 2.0	68	21			X	X		X	X	X
Rc = 3.5	73	25								
Rc = 5.0	79	32								
Rc = 6.0	82	34								
Roof insulation (replace cover)			€/m² NDO							
Rc = 2.0										
Rc = 3.5	102	21			X	X		X	X	X
Rc = 5.0	106	25								
Rc = 6.0	113	32								
	115	34								
Floor insulation			€/m² NBO							
Rc = 1.3	17	13								
Rc = 2.0	19	14			X			X	X	X
Rc = 3.5	22	17								
Rc = 5.0	26	21								
Soil insulation			€/m² NBO							
Rc = 1.3	13	9								
Rc = 2.0	16	11			X			X	X	
Rc = 3.5	25	20								
Rc = 5.0	31	26								

Table 8 Sustainability measures with their effect on IEQ and People: insulation façade, floor and roof

NGO = Netto Geveloppervlakte (Net Façade Surface)
NDO = Netto Dakoppervlakte (Net Roof Surface)
NBO = Netto Begane grondoppervlakte (Net Ground Surface)

5.2 Glazing windows and blinds

Glazing windows have effect on the noise that is heard from outside and the thermal resistance of the window frame. The total effect of the glazing windows is dependent on the ratio of the frame with respect to the total surface of the façade. The lower the U value of the glass, the better the glass insulates. The glazing also allows solar heath and daylight, depending on the number of layers of glass and the type of coating. These properties are expressed in the solar factor (ZTA or g-factor) and the light-entry factor (LTA or TL value). The g-factor indicates the relationship between the incoming and the striking solar radiation (both direct and diffuse radiation). The higher the g-factor, the more sunlight. The fluorescent factor indicates the relationship between the incoming and the visible solar radiation. The higher the TL factor, the more light penetration. Formerly, single glass was used which is developed further to double glass and nowadays triple glass is also used which has a better U value and contributes in realizing a higher Rc value (Israëls & Stofberg, 2015). The different kinds of materials of the window frames have been left out of consideration because of the minimal difference in the result achieved. Additionally, awning blinds also affects the energy label. These blinds can be realised with different materials and techniques. The most important difference is the way of operation. This can be done manually and automatically. Additionally automatic operation can be done also on the basis of solar radiation.

Measure	Costs		Unit	Effect on IEQ				Effect on People		
	Separate intervention	During renovation		Air quality	Thermal comfort	Noise	Lighting	Health	Performance	Productivity
Single glass U = 5.8 Rc = 0.17 G-value = 0.80 TL value = 0.90	0	0	€/m² OG		X	X	X	X	X	
Double glass U = 2.7 Rc = 0.37 G-value = 0.70 TL value = 0.80	149	100	€/m² OG		X	X	X	X	X	
HR U = 1.7 – 2.0 Rc = 0.5 – 0.59 G-value = 0,60 – 0.70 TL value = 0.70 – 0.80	149	100	€/m² OG		X	X	X	X	X	
HR+ U = 1.3 – 1.6 Rc = 0.63 – 0.77 G-value = 0,60 – 0.70 TL value = 0.70 – 0.80	149	100	€/m² OG		X	X	X	X	X	
HR++ U = 1.0 – 1.2 Rc = 0.83 – 1 G-value = 0,60 – 0.70 TL value = 0.70 – 0.80	160	110	€/m² OG		X	X	X	X	X	
HR+++ U = 0.5 – 0.9 Rc = 1.11 – 2 G-value = 0,50 – 0.70 TL value = 0.60 – 0.70	186	134	€/m² OG		X	X	X	X	X	

Awning blinds automatically operated	151	106	€/m² OG		X		X		X	
Awning blinds automatically operated on the basis of solar radiation	186	139	€/m² OG		X		X		X	
Awning blinds manually operated	66	56	€/m² OG		X		X		X	

Table 9 Sustainability measures with their effect on IEQ and People: glazing windows and blinds

OG = Oppervlakte Glas (Surface Glass)

5.3 Heating

Temperature in the building can be increased by heating systems. Especially in the winter season, the indoor temperature can be low. By heating this temperature can be increased to the desired temperature. To generate heat, different techniques can be used. The different techniques and systems which are part of this research are elaborated below:

There are different types of boilers. A CR (Conventional Efficiency) boiler is an (older type) boiler that also makes hot water. CR stands for Conventional Efficiency and has an efficiency between 70 and 80%. The VR boiler (Improved Efficiency) has an efficiency of 83%. An HR (High Efficiency) combi boiler has an efficiency of 90-97.5% . High-efficiency boilers are also upgraded to HR100, HR104 and HR107 boilers. The number here stands for the efficiency (percentage). This efficiency calculates the amount of energy which is used is effective or lost.

Except boilers, heat pumps can also be used for heating. A heat pump extracts heat from the air, soil or groundwater and converts it into usable energy to heat the building. To compare them with each other, the performance is expressed in COP (coefficient of performance) instead of efficiency as with the boilers. This COP now fluctuates between two and five. A COP of three means that the heat pump is capable of producing three kilowatts of heat for every kilowatt that it gets from the electricity grid. Making use of a heat pump makes you eligible for a subsidy. The amount of the subsidy depends on the type of device and on the capacity (Zoethout, 2010).

As last the building can also make use of district heating. District heating doesn't make use of an own heating boiler. The building will receive hot water and heat via a network of water pipes. This is generated by residual heat from, for example, industry.

The instantaneous thermal performance of a system is determined by the Coefficient Of Performance (NL: Prestatiefactor). The COP is a factor reflecting the ratio between the useful heat or cooling obtained in contrast to the energy required . For example, when a heat pump has a COP value of 3, it delivers 3 times as much energy as it actually consumes. Instead of just converting work to heat, it also pumps additional heat from a heat source to where the heat is required. The COP value is the maximum return, in the most favourable situation. The measured value is usually lower than the value provided by the manufacturer because it is determined in the most optimal situation.

$$COP = Q/W$$

Q = is the useful heat supplied or removed by the considered system.
W = is the work required by the considered system

Measure	Costs		Unit	Effect on IEQ				Effect on People		
	Separate intervention	During renovation		Air quality	Thermal comfort	Noise	Lighting	Health	Performance	Productivity
District heating	Afterwards not applicable		€/m² BVO	X	X			X	X	
CR boiler Efficiency: 70% – 80%	Project specific costs		€/m² BVO	X	X			X	X	
VR boiler Efficiency: 83%	Project specific costs		€/m² BVO	X	X			X	X	
High efficiency boiler Efficiency: 90% – 97%	Project specific costs		€/m² BVO	X	X			X	X	
HR-107 boiler Efficiency: 107%	Project specific costs		€/m² BVO	X	X			X	X	
Electric heat pump COP: 2 – 5	Project specific costs		€/m² BVO	X	X			X	X	

Table 10 Sustainability measures with their effect on IEQ and People: heating

BVO = Bruto Vloeroppervlakte (Gross Floor Area)

5.4 Cooling

The usual way to cool an (office) building is with air conditioning using a compression cooling machine. Here the compressor pressurizes a gaseous refrigerant, usually a hydrogen fluorocarbon compound (HFC). When the gas is pressurized, the temperature rises. The refrigerant then flows through a condenser, where it releases heat to the environment. By doing this the gas becomes liquefied. Then the refrigerant flows through an expansion valve. This has two effects: the refrigerant becomes a gas-liquid mixture and the temperature decreases to such an extent that the refrigerant can extract heat from the ventilation air. This is done in an evaporator, in which the medium becomes completely gaseous again. All in all, a compression cooling machine produces no cold. He only moves heat from inside a building to the outside. This is accompanied by high energy consumption (in combination with the compressor).

An alternative to compression cooling is absorption cooling with water as refrigerant. In the evaporator, heat is extracted from an external stream (cold water or a water-glycol mixture). The vapour is then absorbed in a solution with a high concentration of the least volatile component. In addition, heat is released that has to be removed again. This usually happens with cooling water. (Agentschap NL, 2011)

In the case of a heat pump in summer operation, the operation of the heat pump is reversed with a hydraulic circuit. Instead of the heat, the cold is forced into the distribution system.

A heat cold storage works as followed: In winter, the building is heated by a heat pump that extracts heat from the pumped up ground water from the hot spring. The groundwater cools down and is pumped back into the cold source. In summer, this cooled water is pumped up and used as passive cooling. The heated water is returned to the hot spring. The cycle has thus been completed.

Measure	Costs		Unit	Effect on IEQ				Effect on People		
	Separate intervention	During renovation		Air quality	Thermal comfort	Noise	Lighting	Health	Performance	Productivity
Compression cooling	Project specific costs		€/m² BVO	X	X			X	X	X
Absorption cooling	Project specific costs		€/m² BVO	X	X			X	X	X
Heat pump in summer operation	Project specific costs		€/m² BVO	X	X			X	X	X
Heat pump groundwater / wko	Project specific costs		€/m² BVO	X	X			X	X	X

Table 11 Sustainability measures with their effect on IEQ and People: cooling

Other cooling methods as evaporative cooling with water as refrigerant and PCM (Phase Change Material) are not listed in the measure list because these are not simulable in the VABI software.

5.5 Ventilation

Ventilation of a building can be realized by different ways. In this research we will elaborate on natural, mechanical and balanced ventilation.

Natural ventilation takes place through the grid in windows and facades, further via opened windows or via supply and drainage channels. By opening or closing these grids and windows, it's possible to regulate the natural ventilation as required. This method is still the healthiest because the fresh air is supplied directly into the living areas. This system also has a positive influence on the EPC calculations because it does not consume electrical energy. In contrast, more heat (energy) is lost than in balanced ventilation with heat recovery. With this type of ventilation, both the supply of fresh air and the discharge of polluted air run without fans. The supply and discharge are determined by:

- Temperature differences between indoor and outdoor. The natural heat circulation works considerably better in the winter than in the summer, so that windows are much less open in winter than in summer.
- Pressure differences between indoor and outdoor. If there is wind against the window or grid, the ventilation will increase considerably. Open doors and windows have a reinforcing effect.

Natural ventilation (figure 9) has advantages and disadvantages. A big advantage is that the mixing between supplied and discharged air is almost always good. A disadvantage of the system is the limited control exercised over the supply and discharge of air.

A mechanical ventilation system will suck the polluted air through ventilation ducts and discharge it to the outside. Due to the under pressure that is being made, fresh air is brought in through window grids. Internally, the air between the rooms is transported through grids in doors, or through an opening under the doors. Usually an operating switch is placed, with a choice between positions. The ventilation is never switched off.

Balanced ventilation system (figure 10) is based on creating a balance between the supply and removal of air in the building. In a room a ventilation box is placed, which takes care of the discharge of polluted air and the supply of fresh air. Separate energy-efficient fans for supply and discharge are provided in the ventilation box. Supply and discharge are done through ventilation ducts.

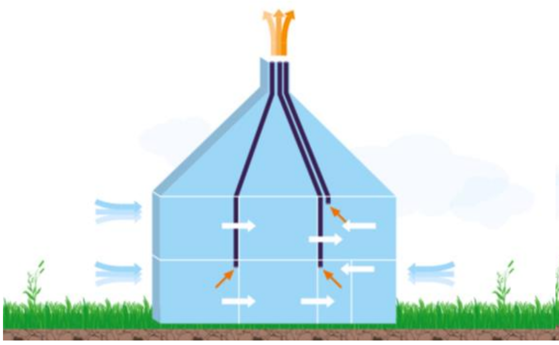

Figure 9 Natural ventilation (RVO, 2014)

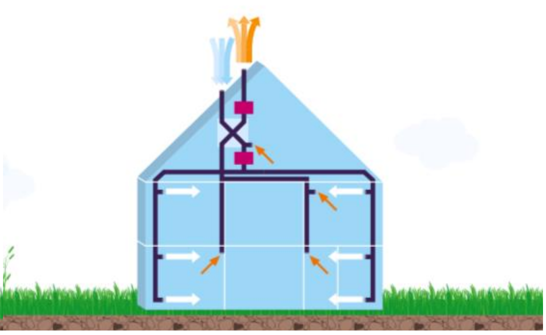

Figure 10 Balanced ventilation (RVO, 2014)

A balanced ventilation system with heat recovery (WTW) reuses a part of the heat, which otherwise disappears via the ventilation system. The polluted air is sucked out of the building by extraction points. The discharged air flows along a heat exchanger. The heat recovery system then uses the heat from the exhaust air to heat up the imported air from the outside. The heated fresh air is blown into the building via pipes to valves.

Measure	Costs		Unit	Effect on IEQ				Effect on People		
	Separate intervention	During renovation		Air quality	Thermal comfort	Noise	Lighting	Health	Performance	Productivity
Natural ventilation	Project specific costs		€/m² BVO	X	X	X		X	X	X
Mechanical extraction	Project specific costs		€/m² BVO	X	X	X		X	X	X
Balanced without heat recovery	Project specific costs		€/m² BVO	X	X	X		X	X	X
Balanced with heat recovery	Project specific costs		€/m² BVO	X	X	X		X	X	X

Table 12 Sustainability measures with their effect on IEQ and People: ventilation

The ventilation systems have different power to ventilate the building. In order to calculate the airflow for a specific system when knowing this power use, the graph of Jackmann (2008) can be used and given in figure 11. In this graph the power of the ventilation unit is expressed to a certain airflow rate. This line is different for the different systems.

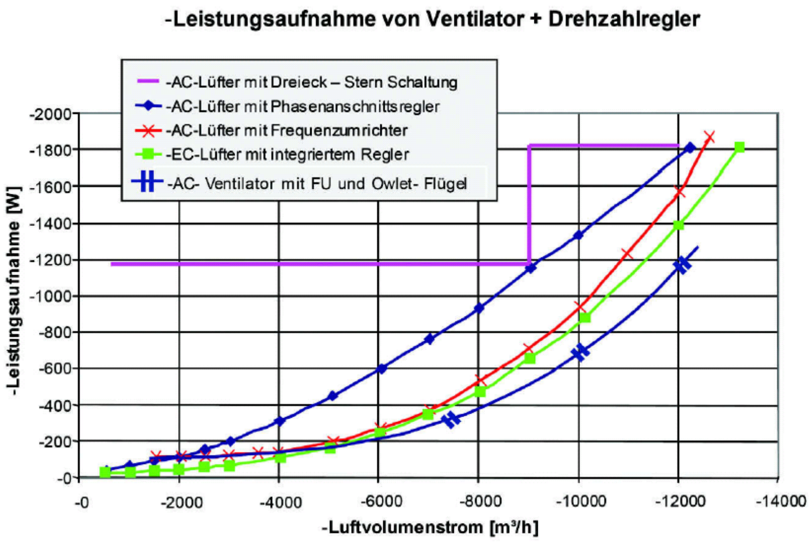

Figure 11 Power consumption versus airflow of mechanical ventilation (Jackmann, 2008)

5.6 Lighting

Lighting can be influenced by the types of lighting fittings and the additional techniques for control (ISSO, 2017). The 3 different types of fittings which are taken into account in this research are conventional lighting (TL-8), TL-5 and LED. The respective energy usage of these fittings are generalised as 15, 10 and 5 W/m².

These fittings can be combined with additional techniques for control. Also, these different techniques can be combined with each other.

- Lighting switch (lighting can be switched off per room)
- Sweep pulse (at a fixed time, the relevant lighting is switched off via a sweeping pulse)
- Presence detection (an infrared sensor detects whether there is movement in a room and switches on the lighting as soon as someone enters the room. If there is no more movement, the lighting switches off)
- Daylight regulation (a light sensor measures the amount of light in the room and then adjusts the artificial light, the sensor can be mounted both per room and per luminaire)

Measure	Costs		Unit	Effect on IEQ				Effect on People		
	Separate intervention	During renovation		Air quality	Thermal comfort	Noise	Lighting	Health	Performance	Productivity
TL-5 lighting (10 W/m²)	20	18	€/m² GO				X	X	X	
LED lighting (5 W/m²)	30	27	€/m² GO				X	X	X	
Lighting switch	0	0	€/m² GO				X			
Sweep pulse	1	1	€/m² GO				X			
Presence detection	6	6	€/m² GO				X			
Daylight regulation	4	4	€/m² GO				X			

Table 13 Sustainability measures with their effect on IEQ and People: lighting

In order to simulate the effects of the measures, combinations have been made of the fittings with the possible techniques. These are the following:

- TL-5 or LED lighting with sweep pulse
- TL-5 or LED lighting with sweep pulse and presence detection
- TL-5 or LED lighting with sweep pulse and daylight regulation
- TL-5 or LED lighting with sweep pulse, daylight regulation and presence detection

5.7 Conclusion

There are several sustainability measures which can be used to improve the energy label and which also influence the indoor environmental quality. These are categorised between Insulation façade, Insulation floor, Insulation roof, Glazing windows and blinds, Heating, Cooling, Ventilation and Lighting. For each category, the effect on the IEQ and People dimension are given. For each building, this list can be used to determine the possible sustainability measure (packages).

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6. Multi Criteria Decision Analysis and Preference Based Design

In previous chapters, the current state, sustainability of office buildings, different opportunities and sustainability measures are presented. This chapter will elaborate on the theory of the model which will be designed. The model which will be designed will be created by the theory of Multi Criteria Decision Analysis (MCDA) and Preference Based Design (PBD) of Binnekamp (2010). Below will be explained what MCDA and PBD are.

6.1 Multi Criteria Decision Analysis

Consideration of different choices or courses of action becomes a Multiple Criteria Decision Making (MCDM) problem when there are a number of norms that conflict with each other (Belton & Stewart, 2003). For example, when you want to buy a phone, relevant criteria may include price, screen size and camera quality. For management decisions at a corporate level, these criteria will be in a wider range. Especially when there are several different interests within the organization.

Multi Criteria Decision Analysis (MCDA) helps to structure the information. It helps decision makers to organize and structure the information in such a way that they can make informed decisions and include all factors in the decision. MCDA is thus an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter. For these decisions an intuitive decision is not sufficient because the conflict between the criteria is too great, or the relevance of the criteria of the various parties involved does not match, or the importance of the criteria is very great (Belton & Stewart, 2003).

MCDA is an aid to decision making, it does not necessarily give the right answer. It seeks to integrate objective measurement with value judgement and makes subjectivity explicit and manageable (Belton & Stewart, 2003). Belton and Stewart (2003) believe, which is shared by many others, that the aim of MCDA is to facilitate decision makers with the learning process about the problem situation, about their own organisational priorities, values and objectives and guide them in identifying a preferred course of action.

There are different problems for which MCDA may be useful (Belton & Stewart, 2003) such as:

- The choice problematique: To make a simple choice from a set of alternatives.
- The sorting problematique: To sort actions into categories such as definitely acceptable, possibly acceptable but needing more information, and definitely unacceptable.
- The ranking problematique: To place actions in some form of preference ordering which might not necessarily be complete.
- The learning problematique: To describe actions and their consequences in a formalized and systematic manner, so that decision makers can evaluate these actions. In which the decision maker seeks simply to gain greater understanding of what may or may not be achievable.
- The design problematique: To search for, identify or create new decision alternatives to meet the goals and aspirations revealed through the MCDA process.
- The portfolio problematique: To choose a subset of alternatives from a larger set of possibilities, taking account not only of the characteristics of the individual alternatives, but also of the manner in which they interact and of positive and negative synergies.

So there is a wide variety of problems that come under MCDA problems. Based on the characteristics, a classification can be made (Belton & Stewart, 2003). These are:
one-off vs. repeated problems, number of stakeholders, status and influence of the client, the ‘problematique’, range of available alternatives and facilitated vs. DIY analysis.
For the practice of MCDA, it is important for the analyst to have a clear understanding of the categories into which the problem falls. This makes it clear which methods and techniques are suitable for the problem and can be used.

The process of MCDA

Within MCDA, a distinction can be made between three important phases (Belton & Stewart, 2003).

1. Identifying and structuring the problem: Before the analysis can begin, the actors will have to develop a common interpretation of the problem, the decision to be made and the criteria by which the decision must be assessed and evaluated.
2. Construction and use of the model: A primary characteristic of MCDA is the development of formal models for preferences, value considerations and goals of the decision-makers, so that alternative measures or considered actions can be compared in a systematic and transparent manner.
3. Development of action plans: An analysis alone does not solve the problem. The results are implemented, which means that the analysis is translated into specific action plans.

Barzilai (2010) has discovered that the existing methods of preference do not have a mathematical foundation. He defines scales on the basis of mathematical operations that are then mathematically applied; strong scales and weak scales. Strong scales are scales where mathematical operations such as addition and multiplication are allowed and weak scales are scales where these mathematical operations are not allowed. This definition is of fundamental value: all scales in the literature on economic and classical measurement theory are weak. Binnekamp (2016) explains this on the basis of the empirical system and mathematical system. An example of this with the scale of Celsius is given in figure 12.

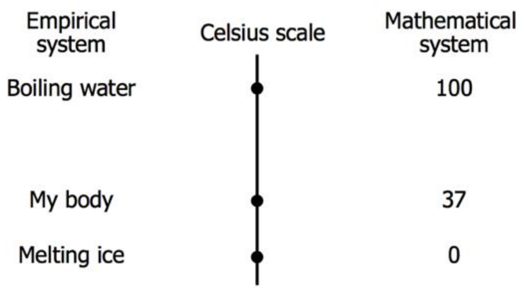

Figure 12 Empirical and mathematical system on the scale of Celsius (Binnekamp, 2016)

The objective of modelling an empirical system on a mathematical system is to enable mathematical operations on the elements of the mathematical system. In short, we want to add mathematical operations such as addition, subtraction, multiplication or division to the numbers. Customary questionnaires ask the respondents to rate certain alternatives on a scale of 1 to 5 on the basis of different criteria. That is comparable with figure 13. Without having reference points, it is said that the body temperature is 37 degrees. The temperature of a body of 37 degrees has no value if you do not know the reference points. That value is therefore undefined, unless you define what empirically the ‘0’ and ‘100’ are.

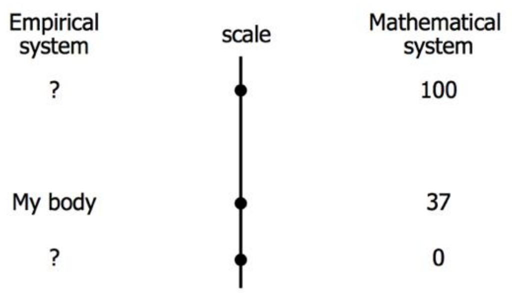

Figure 13 Empirical and mathematical system on the scale of Celsius compared to a scale of 1 to 5 (Binnekamp, 2016)

This is the foundation with which Barzilai (2005) made it possible to measure preference in a mathematically correct manner. Below is a brief description of how this is applied.

6.2 Preference based design

PBD is a design methodology and is based on the method Preference Function Modelling (PFM) of Barzilai (2005).

PFM is an evaluation method. The alternatives are not known in advance and there is a problem that several parties involved have to choose a design that best fits the interest of a group. In order to measure preferences and generate alternatives within the architecture, Binnekamp (2014) has converted the evaluation method PFM into a design methodology called Preference-Based Design (PBD).

Thereafter, they also made it applicable for portfolio management. This portfolio design methodology allows all decision makers to enter their criteria and preferences iteratively and arranges all possible portfolios based on the total preference rating.
PBD has the following procedure which contains 5 steps (Binnekamp, 2010) (Arkesteijn & Binnekamp, 2014):

Step 1: Specify the decision variable(s) the decision maker is interested in.
Step 2: Rate the decision maker's preferences for at least three values for each decision variable as follows:

- a) For each decision variable establish (synthetic) reference alternatives.
  - i) Define a 'bottom' reference alternative, the alternative linked to the value of the decision variable that is least preferred, rated at 0. This defines the origin of the curve, (x0, y0).
  - ii) Define a "top" reference alternative, the alternative linked to the value of the most variable decision variable, rated at 100. This defines the end point of the curve, (x3, y3).
- b) Rate the preference for alternatives associated with the other decision variable values relative to these reference alternatives on the scale established.

Step 3: To each decision variable assign decision maker's weight.
Step 4: Determine the design constraints.
Step 5: Combine decision variable values to generate design alternatives and use the design constraints to test their feasibility.
Step 6: Use the PFM algorithm to yield an overall preference scale of all feasible alternatives.

In PBD design alternatives are described as a combination of decision variables. These alternatives are defined as follows. For each decision variable, a Bezier curve is determined that links the decision variable to the preference rating. Each curve is divided into a number of segments with a number of points on each curve. Combinations of points on each curve thus constitute design alternatives. The x coordinates of these points represent variable values. Design preconditions, with respect to the decision variables, are used to test the design alternatives for feasibility. The y coordinates represent the preferred rating of the decision variables. These are used to determine the total preference rating for combinations of the target variables that are feasible (Arkesteijn & Binnekamp, 2014).

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7. Design

This chapter will elaborate on the design of the model which is created during this research. A sketch of the design will be given, the prototype will be explained and as final the model with will elaborated.

7.1 Model sketch

To give a representation of the model which is created. A sketch of the model has been made with the different elements that it needs to cover. This sketch was the start of the model in order to think about how it should work and what information can be used as input and what output would come.

Sustainability measures	**People**	**Planet**	**Profit**
Insulation façade	Health	Energy usage	Investment costs
Insulation floor	Productivity	Energy label	Subsidy
Insulation roof	Performance		Actual costs
Glazing windows and blinds			Willingness to pay
Heating			Rent
Cooling			Energy costs
Ventilation			Service costs
Lighting			All-in rent
			Payback period
			Value increase

Table 14 Model sketch

7.2 Prototype

Parallel of the research, a model of the sketch is developed. First a prototype has been created to proof that such model can be built by the researcher and to test the way of working of the model. This prototype only contained a few aspects of the sketch and gave a fictive result for three different sustainability measures packages. This prototype contained four sheets:

1. Entry field valuation of the dimensions (People, Planet and Profit) with their subcomponents and criteria
2. Sustainability measures
3. Entry field of the criteria
4. Results sheet model

After this prototype, missing information which is needed as input is gained through desk research and meetings with experts.

7.3 Final model

To help the client in choosing technical packages, a model is developed. This model helps the client finding their own balance in terms of People, Planet & Profit. After that the model will help the client in choosing the best sustainability measure packages in terms of their own balance. The goal of this model is to provide office building owners insight in the opportunities of building renovation and provide structure to their decisions. With this model the client will make decisions with more attention towards IEQ improvement in office building renovation, leading to an optimization of their own People, Planet, and Profit balance. This section presents the structure and way of working of the model. The model contains 7 different sheets which are related with each other.

1. Weighting dimensions and criteria
2. Validation of packages
3. Sustainability measures
4. Criteria People
5. Criteria Planet
6. Criteria Profit
7. Result

Screenshots of the model are presented in Appendix B.

Weighting dimensions and criteria

Each client has a different perspective and own balance within the 3 dimensions. To implement this balance in the model, the dimensions and their criteria can be weighted and filled in the model. This will lead to different unique scores and results for each client when this would be done for the same building. This weighting is done by the client itself or together with advice of an expert. For this weighting, each level/aspects needs to have a total weighting value of 100%.

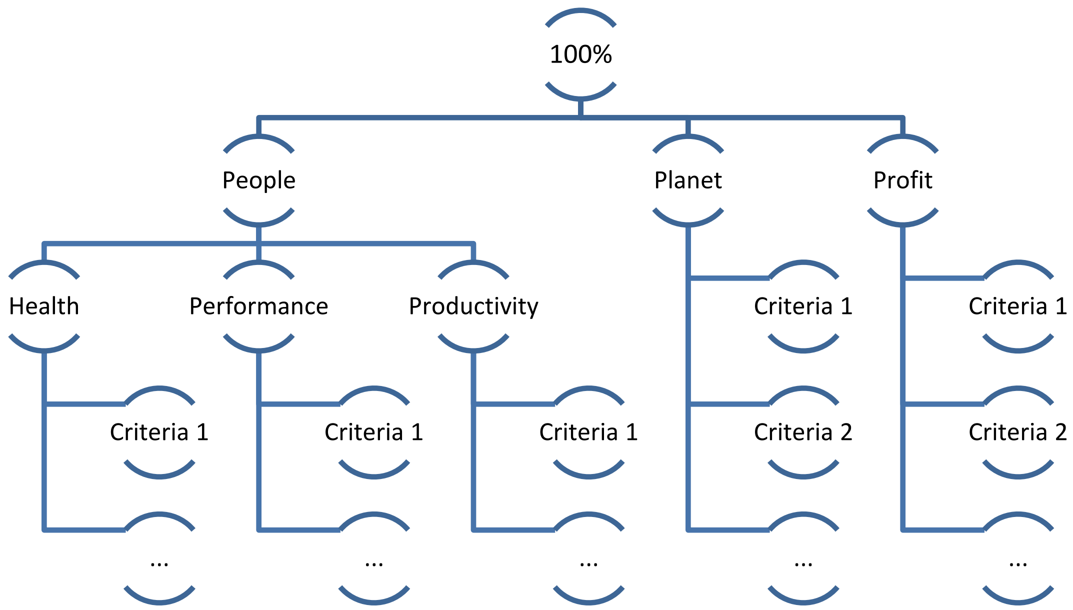

Figure 14 Working of weighting in the model

At the end the different criteria will lead to the scores, when the client doesn't believe in the impact of a criterion it can adjust the weighting of it to its own beliefs.

Validation of packages
Some sustainability measures can't be combined with each other. These restrictions are included in the model and are the following:

- When using one of the heat pump systems, it is recommended to have a shell with a minimum Rc value of 2 and a minimum of double glazed windows. In poorly insulated buildings, a heat pump system is not cost-effective and can cause comfort complaints due to low temperature heating.
- Heat pump in summer operation (Warmtepomp in zomerbedrijf) is only possible if a heat pump on outside air (Warmtepomp op buitenlucht) is used for space heating.
- Heat pump groundwater / wko for cooling is only possible if an electric heat pump is used for space heating because this is a combined system.
- Cooling can only be applied in combination with balanced ventilation.

These restrictions are filled in the model as following: the sustainability measures which can be combined and are compatible with each other can be filled in the schedule in sheet validation. This can be filled in with a 1 and only on the top right corner of the model. During assembly of the technical packages the model than will show if the package combination is compatible.

Sustainability measures
In this sheet the different sustainability measures as described in last paragraph are filled in with their individual effects on the dimensions. This will be done for the following aspects: Insulation façade, Insulation floor, Insulation roof, Glazing windows and blinds, Heating, Cooling, Ventilation, and Lighting. This will help making the technical packages after the current state of the building is determined and the client has implemented their balance of the dimensions. Combining these individual effects doesn't necessarily mean that the total effect will be a sum of all these effects. This is because the effects are not linearly but exponentially and the sustainability measures have dependencies with each other. In order to calculate the exact effect of the measures as described in ISSO 75.1 (ISSO, 2013), the software program VABI will be used. ISSO 75.1 describes how the calculation of an energy label has to be done and is the benchmark of retrieving an energy label. The VABI software is therefore used for calculations when retrieving an energy label.

Criteria People
In this sheet the People dimension will be divided into the subcomponents Health, Performance and Productivity as result of the desk research. Within these findings, criteria have been set up for weighting measures. These criteria will be elaborated below:

<u>Health</u>

Aspect	Subject	Results	Source
Health	Air quality	Doubling outdoor air supply can lead to: - Reduce illness and sick leave prevalence by 10% - Sick leave prevalence from 5 days to 3.8 days per year	(Wargocki, 2011) (Seppänen & Fisk, 2006)
Health	Temperature	Increase of 1°C above 22.5 °C can lead to: - 12% increase in the intensity of SBS-symptoms	(Seppänen & Fisk, 2006)
Health	Lighting	Office workers with windows: - Receive 173% more white light exposure - Sleep 46 minutes more per night	(World Green Building Council, 2014)

Table 15 Key figures impacts of the indoor environmental quality on health

Criterion 1: *Outdoor air supply which affects illness and sick leave***.**

Wargocki (2011) and Seppänen and Fisk (2006) suggest all that doubling the average ventilation rate would decrease the sick leave prevalence in an office. Wargocki states that the effect will be roughly 10% while Seppänen and Fisk say this is around 25%. In this model we will use the conclusions of Seppänen and Fisk (2006) with their exponential function as reference points as given below.

12 L/s per person = 2.0% sick leave (5 days per year)
24 L/s per person = 1.5% sick leave (3.8 days per year)

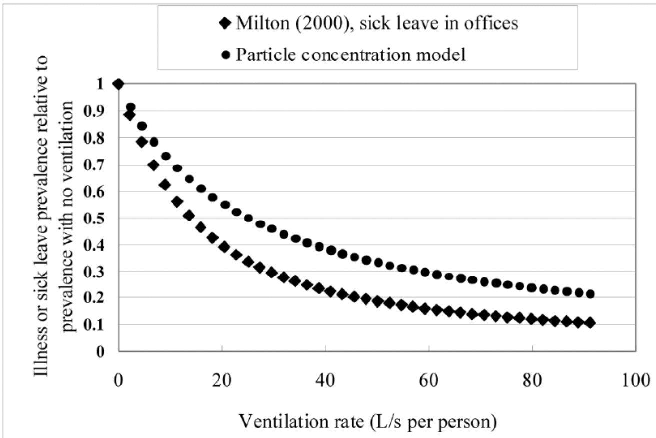

Figure 15 Exponential function illness or sick leave prevalence relative ventilation rate (Seppänen & Fisk, 2006)

Criterion 2: *Temperature which affects intensity of SBS-symptoms.*

Study also has shown that when it gets warmer than 22.5°C there is an increase in the intensity of SBS-symptoms (Seppänen & Fisk, 2006). The sick building syndrome can lead to health complaints such as headaches, dry eyes, sore throat, dry skin, fatigue, lack of concentration and a feeling of dizziness. The ability to control the temperature and keeping the desired temperature on the desired level is dependent by the insulation of the shell and the ability of heating and cooling. This combination will be weighted in criterion 2.

Criterion 3: *Lighting which affects rest and sleep.*

Having daylight is the healthiest light in an office workplace. Lighting affects the sleep and rest of the employee. LED lighting has no stroboscopic effects (flickering or blinking effects), no high voltage peaks and magnetic fields, and no harmful UV radiation (Energeniaal, 2018). This is an improvement compared to fluorescent lighting. Criterion 3 will weight the lighting of the office building.

Criterion 4: *Background noise affecting health.*

The Dutch Green Building Council (2015) state that high background noise result in bad health effects such as a higher adrenaline level which can lead to heart disease. A generalisation can be made that the airborne sound insulation can be linked to the Rc-value of the façade when this is a 'light' façade construction (but not when it's a 'heavy' façade construction because of the mass the façade already has and only when the improvement of Rc-value is done with mineral wool and not plastic sheets such as EPS). The airborne sound insulation of double glazed windows is surprisingly equal and sometimes minimally better than triple glazed windows (van Haaren, 2018). Because this is minimal, glazing are not considered in this criterion. In this research, the reasoning is used that a higher Rc-value of the façade will also lead to a higher airborne sound insulation.

Criterion 5: *Subjective opinion effect on health.*

The last criterion is the subjective opinion of the client without any reference or source. This is implemented because a client can have an overall feeling of a measure package about its influence in terms of health. With implementing this criterion, this gut feeling can be weighted. When the client isn't interested in this, it can be solved by weighting this with 0%.

Performance

Aspect	Subject	Results	Source
Performance	Air quality	Every 10% increase in the percentage satisfied with the air quality: - Increase the performance by 1% - May increase even by 5% from a mediocre level - Increase the performance by 0.8%	(Wargocki, 2011) (Bako-Biro, 2004)
Performance	Temperature	Maximum performance at 21.6 °C. - 4% reduction in performances at cooler temperatures - 6% reduction in performances at warmer temperatures	(Seppänen & Fisk, 2006) (World Green Building Council, 2014)
Performance	Lighting	Exposure to dim light will lead to: - Lose 30% of capacity in a critical brain region temporary	(Henion, 2018)
Performance	Noise	Background office noise can lead to: - 66% drop in performance for a 'memory for prose' task - Take 25 minutes to start again after interruption - Take 8 minutes to get on same concentration level after interruption	(World Green Building Council, 2014) (Dutch Green Building Council, 2015)
Performance		Reduction of central nervous symptoms: - By 7.4% would increase performance by 1.1% - By 10% would increase performance by 5%	(Niemela, Seppänen, & Reijula, 2003) (Wargocki, 2011)

Table 16 Key figures impacts of the indoor environmental quality on performance

Criterion 1: *Background noise affecting performance.*
The World and Dutch Green Building Council both state (2014 and 2015) that background noise result in drop of performance and lost time after interruption. In this criterion is also made use of the reasoning that a higher Rc-value will also have a higher airborne sound insulation (van Haaren, 2018).

Criterion 2: *Lighting which affects brain region.*
As like that lighting affects the health because of the stroboscopic effects, it also has an effect on the performance of the employees.

Criterion 3: *Temperature which affects performance.*
Study also has shown that the optimal temperature is 21.6°C (Seppänen & Fisk, 2006) and when it gets warmer or cooler there is a reduction (4% to 6%) in performances (World Green Building Council, 2014). The ability to control the temperature and keeping the desired temperature on the desired level is dependent by the insulation of the shell and the ability of heating and cooling. Like the effect on health, this combination will be weighted in criterion 3 on the effect of performance.

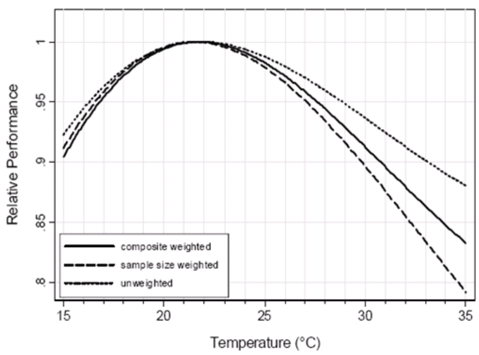

Figure 16 Exponential function relative performance versus indoor temperature (Seppänen & Fisk, 2006)

Criterion 4: *Subjective opinion effect on performance.*
The last criterion is the subjective opinion of the client without any reference or source. This is implemented because a client can have an overall feeling of a measure package about its influence in terms of performance. With implementing this criterion, this gut feeling can be weighted. When the client isn't interested in this, it can be solved by weighting this with 0%.

Productivity

Aspect	Subject	Results	Source
Productivity	Air quality	Doubling outdoor air supply can lead to: - Increased office work by 1.5%	(Wargocki, 2011)
Productivity	Air quality	Air quality can lead to: - 11% gains in productivity - Decrease of the productivity till 10%	(World Green Building Council, 2014)
Productivity	Air quality	1% increase in productivity: - Offset the annual costs of ventilating the building	(Wargocki, 2011)

Table 17 Key figures impacts of the indoor environmental quality on productivity

Criterion 1: *Outdoor air supply which affects productivity*
Wargocki (2011) and the World Green Building Council (2014) suggest all that improving the air quality will lead to gains in productivity. Wargocki states that the effect of doubling this will be roughly 1.5% while the World Green Building Council says that the total improvement can be around 11%. In this model we will start with the conclusions of Wargocki (2011) as reference points and doubling the air supply rate will be as mentioned by Seppänen and Fisk (2006) be from 12 L/s per person to 24 L/s.

12 L/s per person = 100% productivity
24 L/s per person = 101.5% productivity

Criterion 2: *Subjective opinion effect on productivity.*
The last criterion is the subjective opinion of the client without any reference or source. This is implemented because a client can have an overall feeling of a measure package about its influence in terms of productivity. With implementing this criterion, this gut feeling can be weighted. When the client isn't interested in this, it can be solved by weighting this with 0%.

Criteria Planet

In this sheet the Planet dimension will be divided into the subcomponents Energy usage and Energy label as result of the desk research. Within these findings, criteria have been set up for weighting measures. These criteria will be elaborated below:

<u>Energy usage</u>

<u>Criterion 1: *Electricity usage*</u>

The electricity usage of the building can be weighted within this criterion. This usage is given in kWh.

<u>Criterion 2: *Gas usage*</u>

The gas usage of the building can be weighted within this criterion. This usage is given in m^3.

<u>Criterion 3: *Total yearly energy usage*</u>

The total energy consumption of a building will consist of electricity and gas usage. The electricity usage is given in kWh and gas usage in m^3. The total energy consumption will be given in MJ. 1 kWh electricity is equal to 3,6 MJ and 1 m^3 gas is equal to 35,17 MJ. From this we can conclude that the energy use 1 m^3 gas is equal to 9,769 kWh electricity.

<u>Energy label</u>

<u>Criterion 1: *Meets minimum energy label C*</u>

The most important goal of the measures are that the building will get an energy label C. Because of this, the first criterion is if this is the case. When the building will not meet energy label C, the measures package will have a no go.

<u>Criterion 2: *Realistic opportunity for improving label further*</u>

Energy label C will just be the start. Eventually, office building will need to go in the direction of energy-neutral. With keeping that in mind, the criterion where the opportunities for improving the energy label toward energy-neutral will be weighted.

Criteria Profit

In this sheet the Profit dimension will be as result of the desk research and expert interview. Within these findings, criteria have been set up for weighting measures. These criteria will be elaborated below:

Criterion 1: *Investments costs*

Each sustainability measure has a specific investment cost which is different when it will be realized at a separated intervention or during renovation. This is because during renovation, some start-up costs are already made and less needs to be taken into account. The investment costs which are calculated for this research are derivative of the calculations of Arcadis (2016) and can be found in appendix C.

Criterion 2: *Subsidy*

Some sustainability measures qualify for subsidies which are issued by the government. This will make some measures financially more attractive in terms of their investment costs.

Criterion 3: *Actual costs*

In this criterion the actual costs of the investment will be weighted. Here the applicable subsidies will be detracted from the investment costs and the actual costs will be calculated.

Criterion 4: *Rent price*

The different kinds of sustainability measure packages will also lead to different rent prices that the client can gain from a tenant. In this criterion, this difference will be weighted.

Criterion 5: *Willingness to pay*

This criterion will weight the willingness to pay of the tenant after the sustainability measures has been applied.

Criterion 6: *Energy costs*

The sustainability measure packages will also lead, beside the improvement in energy label and the use of less energy, in less energy costs of the building. This financial gain will result in a payback period.

Criterion 7: *Service costs*

In this criterion the service costs of the building will be weighted if these will change because of the sustainability measures.

Criterion 8: *All-in rent price*

In this criterion the share of rent in the total all-in rent price will be weighted. Here the current all-in rent price will be deducted with the new energy costs and service costs. This will result in the new rent price.

Criterion 9: *Payback period*

The financial gains of the sustainability measures (lower energy costs, increase in willingness to pay) are the rental income per m² minus the current rent. The actual costs of the sustainability measures will be divided by the financial gains.

Criterion 10: *Value increase*

If there will be any value increase of the office building. This will be weighted in this criterion.

Results

The results sheet is the output sheet of the model where every input comes together and the sustainability packages can be evaluated with their overall score. By given scores to the criteria, the total score will be calculated with combining this to the weighting of the dimensions, sub-components and these criteria. The total score will be within the range of 0 and 100 as the scores are of the criteria.

8. Case study

In order to test the model, a case study will be held. This will help the development of the model. The case study is an office building which needs to take energy saving measures in order to fulfil the upcoming requirements of minimum energy label C. Also, the case study meets the requirements set in the research proposal to ensure that it fits for its purpose.

8.1 Haagse Arc

The office building 'Haagse Arc' is in The Hague on the Maanweg 174, the location can be seen in figure 17. The building is built in 1992 and is one of the largest office developments in The Hague. The complex is originally composed of three building parts. Where building parts A and C are connected to each other (14,680 m²). The total property comprises approximately 21,471 m² divided over 16 floors. Afterwards building part D, around 2,812 m², is built in order to serve for the International Criminal Court with courtrooms and cellblocks.

Figure 17 Location of Haagse Arc nearby The Hague train station

Figure 18 Air view of Haagse Arc

Figure 19 Front view of Haagse Arc

The office building has currently an energy label F (see appendix A). This label has been given in 2008 and is valid for 10 years. Data of the building has been given by the company Smits van Burgst (2018), who also have given out the energy label in 2008. The general characteristics of the office building and condition of the building are given below.

General building information	
Office building	Haagse Arc
Construction year	1992
GFA (m²)	24.281
Energy label (given at 2008)	F (1.68)
Energy label (with current calculation method)	E (1.59)
Current energy use	22.859.864 MJ
Façade (Rc value) A,B,C – D	1.86 – 2.53
Roof (Rc value) A,B,C – D	2.22 – 2.53
Ground Floor (Rc value)	0.15
Floor above connection (Rc value)	2.65
Glazing window (U-value) A,B,C – D	3.30 – 2.20
Ventilation system	Mechanical balance with heat recovery
Heating installation	VR boiler (water and air)
Humidification system	Steam humidification electric
Cooling system	Compression cooling machine (air)
Tap water system	Electric boiler
Lighting	14.0 W/m2 (average)
Solar energy system	None

Table 18 General characteristics Haagse Arc

When analysing the current characteristics of the building, the possible measures which are applicable of the sustainability measures in this research are given next. These possible measures are given with their costs during renovation and energy effects (calculations at Appendix E) at the Haagse Arc. Measures which are not technically possible, not an option for the client, or would be a downgrade in terms of energy efficiency or equipment are not considered as a possible sustainability measure.

Measures	During renovation	Energy saving MJ	Energy saving %	EPI	Energy costs savings	Payback period
Exterior wall insulation Rc = 3.5 Rc = 5.0	1.747.753 1.800.317	-660.882 -924.600	2,9% 4,0%	1.54 1.52	15.655 19.332	111 93
Interior wall insulation Rc = 3.5 Rc = 5.0	800.256 833.600	-660.882 -924.600	2,9% 4,0%	1.54 1.52	15.655 19.332	81 68
Floor insulation Rc = 1.3 Rc = 2.0 Rc = 3.5 Rc = 5.0	59.150 63.700 77.350 95.550	110.716 33.240 -25.682 -50.384	-0,5% -0,1% 0,1% 0,2%	1.60 1.59 1.59 1.58	0 0 394 774	- - 196 123
Roof insulation (replace cover) Rc = 3.5 Rc = 5.0 Rc = 6.0	123.800 158.464 168.368	-209.740 -338.134 -388.880	0,9% 1,5% 1,7%	1.57 1.56 1.56	3.587 5.554 6.345	35 29 27
HR++ without blinds with awning blinds manual with awning blinds auto. With awning blinds on basis of solar radiation	528.550 797.630 1.037.880 1.196.445	-3.411.524 -3.880.960 -4.045.428 -4.045.428	14,9% 17,0% 17,7% 17,7%	1.35 1.32 1.31 1.31	55.170 36.767 33.828 33.828	10 22 31 35
HR++ + without blinds with awning blinds manual with awning blinds auto. With awning blinds on basis of solar radiation	643.870 912.950 1.153.200 1.311.765	-3.941.942 -4.478.224 -4.653.836 -4.653.836	17,2% 19,6% 20,4% 20,4%	1.31 1.28 1.27 1.27	64.732 47.427 44.678 44.678	10 19 26 29
HR-107 boiler Efficiency: 107%	106.332	-1.424.222	6,2%	1.49	26.481	4
Electric heat pump COP: 2 – 5	165.261	-2.736.938	12%	1.40	143.358	1
Heat pump in summer operation	212.175	-320.280	1,4%	1.57	1.504	141
TL-5 lighting with sweep pulse with sweep pulse and presence detection with sweep pulse and daylight regulation with sweep pulse, daylight regulation and presence detection	461.339 607.025 558.463 704.149	-2.786.354 -3.503.066 -3.151.402 -3.834.334	12,2% 15,3% 13,8% 16,8%	1.40 1.35 1.37 1.32	18.221 22.886 19.769 24.193	25 27 28 29
LED lighting with sweep pulse with sweep pulse and presence detection with sweep pulse and daylight regulation with sweep pulse, daylight regulation and presence detection	582.744 728.430 679.868 825.554	-4.809.534 -5.162.404 -4.991.120 -5.307.580	21,0% 22,6% 21,8% 23,2%	1.25 1.23 1.24 1.22	31.168 33.566 32.040 34.220	19 22 21 24

Table 19 Possible sustainability measures Haagse Arc

Here can be seen that big steps towards the new legislation can be made by changing the lighting of the building into LED lighting, change the glazing or install an electric heat pump. But in order to realise energy label A, 6 sustainability measure packages are composed together with experts and the client. In order to compose these sustainability measure packages, boundaries have been set up by the client. These boundaries were the following:

- Changes made at once
- Maximum payback period of 20 years
- Energy label A
- Budget of € 3.000.000, Maximum costs of €4.000.000 but payback period boundary stays the same

This has led to the following sustainability measure packages:

<u>Package 1:</u> 1. No changes in façade 2. No changes in roof 3. HR++ glazing 4. No changes in heating 5. Heat pump in summer mode 6. No changes in ventilation 7. Led lighting with sweep pulse	**<u>Package 2:</u>** 1. Interior wall insulation Rc 3.5 2. No changes in roof 3. HR++ glazing with manual awning blinds 4. No changes in heating 5. Heat pump in summer mode 6. No changes in ventilation 7. Led lighting with sweep pulse	**<u>Package 3:</u>** 1. Interior wall insulation Rc 3.5 2. Roof insulation Rc 5.0 3. HR++ glazing with manual awning blinds 4. Electric heat pump 5. Heat pump in summer mode 6. No changes in ventilation 7. Led lighting with sweep pulse and daylight regulation
<u>Package 4:</u> 1. Interior wall insulation Rc 3.5 2. Roof insulation Rc 5.0 3. HR+++ glazing with manual awning blinds 4. Electric heat pump 5. Heat pump in summer mode 6. No changes in ventilation 7. Led lighting with sweep pulse	**<u>Package 5:</u>** 1. Interior wall insulation Rc 5.0 2. Roof insulation Rc 5.0 3. HR+++ glazing 4. Electric heat pump 5. No changes in cooling 6. No changes in ventilation 7. Led lighting with sweep pulse	**<u>Package 6:</u>** 1. Interior wall insulation Rc 5.0 2. Roof insulation Rc 5.0 3. HR+++ glazing with manual awning blinds 4. Electric heat pump 5. Heat pump in summer mode 6. No changes in ventilation 7. Led lighting with sweep pulse and daylight regulation

Table 20 Sustainability measure packages Haagse Arc

The packages have their own energy (label) and financial consequences. These are calculated with the VABI software or within the model with the use of the derivative of the calculations of Arcadis (2016) and are given in table 21.

Package	Energy use	Energy savings in %	EPI	Label	Actual costs	Financial gains per m^2	Payback period
1	14.123.718	38,2%	0.98	A	1.323.469	8,3	7,4
2	13.345.992	41,6%	0.93	A	2.392.805	7,7	14,4
3	11.326.922	50,5%	0.79	A	2.813.655	13,6	9,7
4	11.095.872	51,5%	0.77	A	2.831.851	13,6	9,7
5	11.875.375	48,1%	0.83	A	2.383.939	13,8	8,1
6	10.744.747	53,0%	0.75	A	2.962.319	13,7	10,1

Table 21 Energy and financial result of sustainability packages

The results of each package will be given in following section were the criteria are weighed.

8.2 Weighting of the dimensions

As concluded from the desk research, each organisation has their own balance within the dimensions People, Planet & Profit. Because of this, the dimensions are weighted by the client within their goals and objectives of their organisation. This weighting has done several times in a so-called calibration session. Eventually, this has given the following weighting for the Haagse Arc casus:

People	45%	Health	30%	Outdoor air supply which affects illness and sick leave	30%	*4,05%*
				Temperature which affects intensity of SBS-symptoms	30%	*4,05%*
				Lighting which affects rest and sleep	35%	*4,73%*
				Subjective opinion effect on health	5%	*0,67%*
		Performance	40%	Background noise affecting performance	30%	*5,40%*
				Lighting which affects brain region	35%	*6,30%*
				Temperature which affects performance	30%	*5,40%*
				Subjective opinion effect on performance	5%	*0,90%*
		Productivity	30%	Outdoor air supply which affects office work	80%	*10,8%*
				Subjective opinion effect on productivity	20%	*2,70%*
Planet	10%			Total yearly energy usage in MJ	75%	*7,50%*
				Realistic opportunity for improving label further	25%	*2,50%*
Profit	45%			Investments costs	0%	
				Subsidy	0%	
				Actual costs	20%	*9,00%*
				Rent	0%	
				Willingness to pay	10%	*4,50%*
				Energy costs	0%	
				Service costs	0%	
				All-in rent price	50%	*22,5%*
				Payback period	10%	*4,50%*
				Value increase	10%	*4,50%*

Table 22 Weighting dimensions Haagse Arc

As can be seen, the client prefers the dimensions People and Profit equally (45%). The client has the opinion that the Planet dimension is only important because the new legislation and when this is achieved, this isn't as important as the People and Profit dimension. Here can be seen that the all-in rent price, outdoor air supply, actual costs of investment are the most important and influencing factors (46,5%) of the outcome in the model.

8.3 Weighting of the criteria

The different criteria need to be weighted in order to compare the different sustainability measures packages. This is done together with the client. Below will be elaborated what the reference and preference points of the criteria are as elaborated by Binnekamp (2016).

Criteria People

Health

Criterion 1: *Outdoor air supply which affects illness and sick leave*.

The outdoor air supply which are used frequently within office buildings are between 6 L/s and 30 L/s. These are the bottom (0) and top (100) reference points. Given the desk research of Wargocki (2011) and Seppänen and Fisk (2006), the client has given a reference point (50) of 18 L/s.

The current outdoor air supply of the office building is read from the chart of Jackmann (2008) and calculated with use of the occupancy rate of the building. This has given a current outdoor air supply rate of 22 L/s.

Criterion 2: *Temperature which affects intensity of SBS-symptoms.*

In order to weight this criteria, the ability of the shell and the presence of cooling to keep the temperature below 22.5°C are considered. In order to reach this in the summer, cooling is needed. In collaboration with an expert and the client, reference points are given with corresponding insulation values, g-factor of the glazing and heating and/or cooling systems.

Situation	Insulation value façade	G-factor glazing	Cooling	Rating
Worst	1.86 – 5	0.70	None	0
Bad	3.50 – 5	0.70	Present	75
Reasonable	1.86	0.70	Present	86
Good	3.50 – 5	0.60 (HR+++)	Present	88
Optimal	1.86	0.60 (HR+++)	Present	100

Table 23 Situations to control the temperature which affects intensity of SBS-symptoms with their rating

Criterion 3: *Lighting which affects rest and sleep.*

In order to weight the criteria of lighting which affects rest and sleep, the different fittings are considered. In collaboration with an expert and the client, reference points are given.

Fittings	Rating
Conventional lighting	0
TL-5 lighting	50
TL-5 lighting with daylight regulation	70
Led lighting	85
Led lighting with daylight regulation	100

Table 24 Lighting fittings with their rating in order to weight criterion lighting which affects rest and sleep

Criterion 4: *Background noise affecting health.*

In this research, we assume that the background noise will be reduced when the Rc-value of the façade increases. This gives us a bottom reference point (0) at Rc 1.86 and top reference point (100) at Rc 5. The client has given a reference point (60) at Rc 3.50.

Criterion 5: *Subjective opinion effect on health.*

The last criterion about health is the subjective opinion of the client. This weighting has done several times in a so-called calibration session between the different sustainability measures packages. The different packages are compared with each other and evaluated.

Performance

Criterion 1: *Background noise affecting performance.*
In this research, we assume that the background noise will be reduced when the Rc-value of the façade increases. This gives us a bottom reference point (0) at Rc 1.86 and top reference point (100) at Rc 5. The client has given a reference point (50) at Rc 3.50.

Criterion 2: *Lighting which affects brain region.*
In order to weight the criteria of lighting which affects brain region, the different fittings are considered. In collaboration with an expert and the client, reference points are given.

Fittings	**Rating**
Conventional lighting	0
TL-5 lighting	50
TL-5 lighting with daylight regulation	70
Led lighting	85
Led lighting with daylight regulation	100

Table 25 Lighting fittings with their rating in order to weight criterion lighting which brain region

Criterion 3: *Temperature which affects performance.*
Seppänen and Fisk (2006) stated that the optimal temperature is 21.6°C. The sustainability measures which can realize this on a constant level will be the top reference point (100). The bottom reference point (0) is where it gets colder than 17°C and warmer than 27°C and the performance decreases with 5%. Given the graph of Seppänen and Fisk (2006), the client has given a reference point of lower than 18,5 °C and higher than 24 °C with the rating 50.

Criterion 4: *Subjective opinion effect on performance.*
The last criterion about performance is the subjective opinion of the client. This weighting has done several times in a so-called calibration session between the different sustainability measures packages. The different packages are compared with each other and evaluated.

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Productivity

Criterion 1: *Outdoor air supply which affects productivity*
The outdoor air supply which are used frequently within office buildings are between 6 L/s and 30 L/s. These are the bottom (0) and top (100) reference points. Given the desk research of Wargocki (2011) and Seppänen and Fisk (2006), the client has given a reference point (33) of 12 L/s.

The current outdoor air supply of the office building is read from the chart of Jackmann (2008) and calculated with use of the occupancy rate of the building. This has given a current outdoor air supply rate of 22 L/s.

Criterion 2: *Subjective opinion effect on productivity.*
The last criterion about productivity is the subjective opinion of the client. This weighting has done several times in a so-called calibration session between the different sustainability measures packages. The different packages are compared with each other and evaluated.

Criteria Planet
Energy usage

Criterion: *Total yearly energy usage*
The current yearly energy consumption of the building is 22.859.864 MJ which will be used as bottom reference point (0). The best score of the sustainability measures packages is 10.744.747 MJ which will be referred as top reference point (100). The client has given a reference point (50) of 18.000.000 MJ which corresponds for an energy label C for the building.

Energy label

Criterion: *Realistic opportunity for improving label further*
Energy label C will just be the start and is the bottom reference point, where the optimal label A++ is referred as the top reference point. The labels between are rated by the client and given below:

Label	Rating
No possibility to improve from C	0
Possibility to improve to B	25
Possibility to improve to A	90
Possibility to improve to A+	95
Possibility to improve to A++	100

Table 26 Rating in order to weight criterion realistic opportunity for improving label further

Criteria Profit

Criterion 1: *Actual costs*

The client has a budget of € 3.000.000 to reach energy label A which will be referred as reference point (50). While composing the technical packages, alternatives were proposed which had a maximum costs of € 4.000.000 which will be used as bottom reference point (0) and a minimum of € 1.000.000 which will be used as top reference point (100).

Criterion 2: *Willingness to pay*

The client believes that future tenants are willing to pay more rent because the energy label will improve towards A. But he thinks that there will be no difference in willingness to pay when energy label A has been reached. The current rent price is €100,- which will be used as bottom reference point (0) and the maximum willingness to pay of tenants is a rent price of €105,- which is the top reference point (100). The client has set up a rent price of €103,- as reference point (50).

Criterion 3: *All-in rent price*

The current all-in rent price of the building is structured as following per m² per year: € 100,- rent, € 28,- energy costs and € 8 service costs. This results in an all-in rent price of € 136,-. The expected rent price when the building will have an energy label A is the same as the willingness to pay (€ 105). Because the client opts for an all-in rent price, the savings on energy costs will result in a higher rental income when you use an all-in rent price. This has result in the following rent prices:

Package	Energy costs savings per m²	Rental income per m²
1	3,3	108,3
2	2,7	107,7
3	8,6	113,6
4	8,6	113,6
5	8,8	113,8
6	8,7	113,7

Table 27 Sustainability packages with their energy costs savings and rental income per m²

The willingness to pay is €105 which will be referred as bottom reference point (0), while the client opts for a most favourable rental income of €120 which will be referred as the top reference point (100). The client has given a reference point (40) of €110.

Criterion 4: *Payback period*

The financial gains of the sustainability measures (lower energy costs, increase in willingness to pay) are the rental income per m² minus the current rent (100 per m²). This value will be used to calculate the payback period. The actual costs of the sustainability measures will be divided by the financial gains.

Package	Actual costs	Financial gains per m²	Payback period
1	1.323.469	8,3	7,4
2	2.392.805	7,7	14,4
3	2.813.655	13,6	9,7
4	2.831.851	13,6	9,7
5	2.383.939	13,8	8,1
6	2.962.319	13,7	10,1

Table 28 Sustainability packages with their actual costs, financial gains per m² and payback period

The client prefers that his investments will pay as quickly as possible. Within these alternatives this is package 1 with a payback period of 7,4 years and this will be referred as top reference point (100). The client has the opinion that a payback period of 20 years will be too long and this will be used as bottom reference point (0). He defined a payback period of 10 years as reference point (50).

Criterion 5: *Value increase*
The client believes that changes in energy label will also lead to a (small) increase in value of the building. He defined his preference as following:

Label	Ranking
D or lower	0
C	70
B	90
A	100

Table 29 Energy labels with their rating in order to weight criterion value increase

8.4 Results

By weighting the dimensions and criteria, the different sustainability measures packages can be compared with each other. After weighting the different dimensions and the criteria, the model will give an outcome which will be as explained in previous chapter a value between 0 and 100. The results for the different dimensions for the Haagse Arc are given in table 29. Detailed score of each dimension are given in appendix F.

Package	People (45%)	Planet (10%)	Profit (45%)	Total score (100%)
1	67	85	62,83	66,85
2	77	85	48,33	64,88
3	79	98	69,28	76,67
4	79	99	69,37	76,44
5	85	96	76,02	82,08
6	89	100	67,92	80,56

Table 30 Results of the case study

Here can be seen that the packages score different on the different dimensions. Sustainability measure packages 5 has the highest total score while this package doesn't score the best in the People and Planet dimensions. On the other side, package 6 scores the best within the People and Planet dimension but because of its score on Profit, it doesn't come out as the best scoring package.

Evaluation

When evaluating the results of the case study, the packages have been compared with their scores to get a sense of the sensibility within the model. This is done with package 3 till 6 because their scores are relatively close (under 6%) with each other.

	People										Profit				
	45%										45%				
	Health				Performance				Productivity						
	30%				40%				30%		100%				
Package	Cr 1	Cr 2	Cr 3	Cr 4	Cr 1	Cr 2	Cr 3	Cr 4	Cr 1	Cr 2	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5
	30%	30%	35%	5%	30%	35%	30%	5%	80%	20%	20%	10%	50%	10%	10%
3	67	75	100	70	50	100	80	90	76	90	57	100	64	56	100
4	67	88	85	90	50	85	85	100	76	100	57	100	65	56	100
5	67	88	85	95	100	85	89	100	76	100	73	100	66	86	100
6	67	88	100	100	100	100	89	100	76	100	52	100	65	49	100

Table 31 Score sustainability packages on People and Profit

Here can be seen that the different packages score on some criterion equally. This means that a change in the score of these criteria will not have any effect on the outcome of the model. To get a sense on what kind of effect these scores have on the total score. The share of each criterion in the total score is given in table 31.

	People										Profit				
	Health				Performance				Productivity						
Package	Cr 1	Cr 2	Cr 3	Cr 4	Cr 1	Cr 2	Cr 3	Cr 4	Cr 1	Cr 2	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5
3	2,7	3,0	4,7	0,5	2,7	6,3	4,3	0,8	8,2	2,4	5,2	4,5	14,5	2,5	4,5
4	2,7	3,6	4,0	0,6	2,7	5,4	4,6	0,9	8,2	2,7	5,1	4,5	14,6	2,5	4,5
5	2,7	3,6	4,0	0,6	5,4	5,4	4,8	0,9	8,2	2,7	6,5	4,5	14,8	3,9	4,5
6	2,7	3,6	4,7	0,7	5,4	6,3	4,8	0,9	8,2	2,7	4,6	4,5	14,7	2,2	4,5

Table 32 Share of criterion given in percentages (sum of all is equal to the final score)

Here can be seen that with the weighting of the dimensions and criteria, a score of 64,4 is fixed (74 when you add People in). The differences in variable score are given in table 32. Here can be seen that there are three criteria which vary above 1% and one criterion of Profit which has a huge share on the total score (around 14%) but don't differ a lot from each other. These criteria are evaluated and weighed again with the client.

	People										Profit				
	Health				Performance				Productivity						
Package	Cr 1	Cr 2	Cr 3	Cr 4	Cr 1	Cr 2	Cr 3	Cr 4	Cr 1	Cr 2	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5
Variable	0	0,6	0,7	0,2	2,7	0,9	0,5	0,1	0	0,3	1,9	0	0,3	1,7	0

Table 33 Variety in score

This has led to changes in reference points of the different criterion. Criterion 1 of performance gained a reference point of 50 for an Rc value of 2 instead of 3.5. Criterion 4 of profit gained a top reference point (100) of 5 year instead of 7 so that a difference of 1 year payback period will not lead to such diversity in scores. Also the client changed his belief in the weighting of Actual costs (20%), All-in rent price (50%) and payback period (10%) to the weighting of 25%, 30% and 25%. These changes have led to the scores in table 33.

Package	People (45%)	Planet (10%)	Profit (45%)	Total score (100%)
1	71	85	70,69	72,09
2	81	85	51,07	67,96
3	83	98	66,91	77,41
4	83	99	66,87	77,12
5	85	96	74,75	81,50
6	89	100	64,89	79,19

Table 34 Results after evaluation case study

Here can be seen that the scores did change but that the ranking of the packages are still the same. The model its outcome isn't sensitive for the changes in weighting the criterion. The preferred package will stay the preferred one.

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9. Conclusion

In this part of the research, answer is given on the main research question and the sub questions. After this, limitations and recommendations are provided that can be followed in future work.

9.1 Conclusion

Climate strategies and targets pressure countries to improve energy efficiency in Dutch office buildings. This is partly included in legislation for the year 2023 and will be continued in upcoming years with the ambition to have zero energy buildings by 2050. Nowadays, more than half of the office buildings do not meet the requirements of the government. Investments must be made by office building owners to meet these energy labels while they have not taken these investments into account (financially). Furthermore owners do not have the (necessary) knowledge regarding energy labels and sustainability. Office building owners want to know whether investments can be made from a broader sustainability perspective within the value areas People, Planet and Profit that are also financially justified. To know this office building owners need to be facilitated knowledge and insight in the effects and opportunities of sustainability measures. Given this problem, the following research question is formulated:

How can an office building owner make informed decisions on the sustainable development of his building to achieve minimum energy label C, resulting in an improved balance between the value areas People, Planet and Profit given the objectives of the organization?

Throughout this thesis, the following sub research questions are answered. A conclusion on each sub question is presented here.

1. What is the current state of the Dutch office building stock?

Office buildings have the largest energy saving potential (22%) within the service sector in the Netherlands. Estimations are that 52,6% of the office building supply needs to improve the energy label in order to meet this upcoming legislation (Arnoldussen, van Zwet, Koning, & Menkveld, 2016). This share is characterized by older buildings which are performing poorly in terms of energy efficiency. The autonomous development of the office stock will not be sufficient in order to meet the new legislation and measures need to be taken by office building owners.

2. What does sustainability mean for office buildings?

Sustainable development balances people's needs while protecting the environment for the present and future generations. This protection of the environment is done with the impact the office buildings have on the environment. With this reasoning, sustainability can be defined as environmental sustainability as defined by Morelli (2011). This research study maintains the triple bottom line theory by John Elkington (1994).
The People dimension refers to the indoor environmental quality and the impact this has on the users of the building which are for the most part employees. The Planet dimension stands for the energy use of the office building. And the Profit dimension is about creating economic value with the sustainability measures as in a higher return on investment. Also, the impact that the IEQ has in terms of health, productivity and performance is elaborated which can be seen as opportunities and threats.

3. What are the (subsidy) opportunities in office building renovation and what does an improved energy label mean in terms of People, Planet & Profit?

The opportunities can be divided into technical, financial and organizational opportunities. Savings in up to 18 m^3 gas and 29 kWh electricity usage per m^2, lifetime extension, perspective towards energy label A and modern technique are technical opportunities. Increase in rent price and market value, lower energy costs from 1 till 13 € per m^2 per year, financing and subsidy are the financial opportunities. More control, strengthen competitive position, attract tenants and their employees and a better work environment are organizational opportunities.

4. What (generic combination) of technical sustainability measures can improve the sustainability and what effect will it have in terms of People, Planet & Profit?
Generic sustainability measures can be combined into project specific sustainability measure packages. These are presented in terms of People (IEQ), Planet (energy efficiency) and Profit (investment costs, rent price, energy costs, payback period and value increase).

5. How can technical, financial and organizational opportunities be evaluated by office building owners?
A model is designed that can be used in comparing several sustainability measures packages. The model is inspired by Multi Criteria Decision Analysis (MCDA) and Preference Based Design (PBD) of Binnekamp (2010). PBD is a design methodology and is based on the method Preference Function Modelling (PFM) of Barzilai (2005). The objective of the model is to enable mathematical operations on different elements. By using the model, office building owners consider their organizational interests and objective in the dimensions People, Planet & Profit.

6. To what extent does insight in effects of sustainability measures in improved return on investment?
When the client wouldn't opt for an all-in rent price, the tenant would pay a rent price of €105,- per m² and the benefits of the energy savings measures will be in favour of the tenant. By opting for an all-in rent price the client can gain more rental income without having the tenant paying more than at this moment (rent + service costs + energy costs). This will lead to the following increase in Return on Investment as given in table 34.

Package	Actual costs (€)	Financial gains per year	Increase in Return on Investment (%)
1	1.323.469	70.854	5,35%
2	2.392.805	57.972	2,42%
3	2.813.655	184.651	6,56%
4	2.831.851	184.651	6,52%
5	2.383.939	188.945	7,93%
6	2.962.319	186.798	6,31%

Table 35 Increase in Return on Investment

Answering the main research question:

How can an office building owner make informed decisions on the sustainable development of his building to achieve minimum energy label C, resulting in an improved balance between the value areas People, Planet and Profit given the objectives of the organization?

The upcoming legislation to achieve minimum energy label C in 2023 makes office building owners compelled to think about their own building portfolio. The decision making in which to invest is therefore a big question mark. The model which is designed will help the building owner in this decision making process.
Each organization or client has their own balance between the value areas People, Planet and Profit. Because of this, the balance between these areas can be implemented in the model so that this will be taken into account. This weighting between these value areas will influence the final score and recommendation of best suitable sustainability package. Also, within these value areas, criteria have been set up to weight the packages in these value areas. As done with the weighting of the value areas before, this will also be done for these criteria. By doing so, the balance between the value areas and within these value area will be clear in the decision making. This will lead that informed decisions can be made on the sustainable development of the building which fits the best between the value areas People, Planet and Profit given the objectives of the organization or client.

9.2 Limitations & Recommendations

This research has been a graduations thesis with limited time and resources. These limitations are elaborated together with recommendations for future work.

First, this research has only looked at the energy performances of the building after the sustainability measures. To create true sustainability, this must be viewed in a broader sense as described by Morelli (2011). Except energy performance, also user behaviour, used materials and the re-use of materials needs to be considered. Also, instead of only giving an energy label to a building, giving also an label of the wellness level of a building will give more insight in the qualities of the building. To do so, different levels need to be defined which can be implemented in the model. By doing so, the model can show the new wellness level when performing a technical measure.

The model which is designed can be improved and optimized on different levels. First, by investing more time and money, scripts can be written to create software which can be used by other office buildings owners. Also the manual operations within the model will be mitigated and the model will work fully automatic. Also, when doing this, an algorithm can be implemented within the software so that every possible outcome of the model will be calculated. This can be integrated with the restrictions of packages which are also in the current model. To do so, packages wouldn't need to be made by specialists and can be made by the model itself.

Changes in the energy label are currently calculated separately with special designed software. Integration with special energy label software, such as the used software VABI, should be an improvement in order to create fully automatic software.

The used VABI software also has its limitations. Some possible technical measures can't be simulated such as PCM's and are left out of consideration within this research.

The current way of calculating the energy label is also open for discussion. There are many holes in the way that this label is given. Many installations are used with standard values and not the real values in the software. This can give a non-realistic image about the sustainability measures and their impact. There is a new way of determination of energy label in the making which is planned to be released in 2020. This is according to NTA8800 and still developing. Around 80% of the new method is already known and the expectation is that this will be 90% at the end of 2018. This new way of determination of energy label needs to be implemented within this model, preferably in an automatic model.

Criteria have been set up from literature. These can always be improved or change because of the popularity of the subjects at this moment. It's recommended that when a user is willing to use the model, he should check if the used literature and figures are not improved by a new research.

With the model which is designed, the decision making question will be a big question mark, mostly because the financing of these investments. In order to make the investments more attractive for the building owner, financial benefits of the investments as in lower energy costs should be in advantage for the client. The client needs to opt for an all-in rent price.

The calculated energy costs and energy savings may deviate from reality. This can result in a deviation from the calculated payback period and return on investments. Financial gains retrieved from improvements in health, productivity and performance are not implemented in the model because these are 'soft' factors. These can be implemented if the client opts for doing this.

Currently assumptions have been made. In future work, in depth research about the sound insulation can be held to weight these criteria.

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Appendix A

Current energy label

Appendix B

Final model

Appendix C

Costs of sustainability measures

Appendix D

VABI sustainability measures

Appendix E

VABI sustainability packages

Appendix F

Case study in model