Exploiting the energy saving potential of non-residential corporate property by adopting a new strategy to building maintenance and repair

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Management summary

In the Dutch non-residential building stock there is a large energy saving potential. Besides the reduction of energy consumption and consequently carbon emission being vital in mitigating climate change, the potential also implicates a large potential financial gain. Nonetheless, the potential is not exploited due to a lack of commitment to energy reduction, the financial gain for corporate organisations being relatively low and the presence of practical barriers. Building maintenance is an existing activity within corporate property management that offers possibilities to improve property energy efficiency and so reduce the use of energy. With the aim to contribute to solving the problem of unexploited opportunities to reduce energy consumption, the main research question was posed: *How can the opportunities to improve energy efficiency within maintenance activities of existing non-residential property be exploited?*

Building maintenance and repair (BMR) can improve property energy efficiency if its management objective is extended. Additional to the preservation of the technical functionality of all service systems and building components, BMR should also focus on the optimisation of energy efficiency. This means that preventative maintenance is performed to ensure the technical functionality and energy efficiency, and replacement and new placement of building elements is done either when the technical lifetime of the element has ended, or when early replacement can improve energy efficiency. The maintenance schedule offers a large opportunity to involve energy reduction measures within the future maintenance activities. Improvement opportunities can be identified by 1) determining energy inefficiencies, 2) identifying energy inefficient components and 3) determining the technical solutions that can eliminate these inefficiencies. Essential in the identification phase is the insight in energy consumption and the availability of property information and specific technological knowledge. Assessment of identified opportunities ideally is performed using financial as well as qualitative criteria such as the effects on indoor environmental quality and corporate image. Financial valuation should be performed using sophisticated methods e.g. life cycle costing and discounted cash flow while taking future uncertainties into account.

Multiple problems arise regarding the assessment of improvement measures. First of all, multiple solutions are possible to eliminate energy inefficiencies, for example regarding the technology and the moment of implementation. This means that for an entire building, many combinations of solutions are possible. Furthermore, these measures can be assessed using multiple criteria and valuation methods, of which sophisticated financial valuation methods require more complex calculations. The value of measures is also influenced by environmental factors such as future price increases. Another problem within current assessment approaches is the isolation of improvement measures, while the measures are part of a range of expenditures. Especially when improvement measures are considered as a part of maintenance activities, insight in all maintenance expenditures is required to make decisions on the complete overview of costs. The above problems hamper sophisticated assessment of measures and therefore, a support tool is developed that provides help in performing the assessment of a combination of interventions.

The development of a dynamic assessment tool aims helping organisations in assessing energy efficient maintenance scenarios that include multiple energy efficiency interventions as a part of other maintenance activities. By the use of System Dynamics, a tool was developed in the software package Vensim PLE Plus. A User Interface guides the tool user through the required steps in which the model settings can be adjusted accordingly. The tool is tested using a case study into the City Hall of Nijmegen, the Netherlands, for which the basic maintenance scenario is compared to an energy efficient maintenance plan including nine efficiency interventions. The assessment tool shows that over a period of 20 years, the net present value of the energy efficient scenario is 5% higher in value than the traditional maintenance plan, while energy consumption and carbon emission decreases consecutively 25% and 20%. The tool was verified by expert interviews in the municipal sector and consultancy sector.

This research has resulted in describing how maintenance activities can contribute to energy efficiency by embedding energy improving interventions within the existing maintenance planning. The assessment of an energy efficient maintenance scenario for the case study of the Nijmegen City Hall, shows that the new strategy cost effectively reduces energy. The most important practical implication to property management is 1) to consider whether within corporate real estate management a new maintenance strategy can be adopted by assessing, with the use of the assessment tool, what the long-term effects are for one or more maintenance scenarios. Besides that, 2) insight in energy consumption should be gained to create awareness, to provide solid ground to base decisions on, and to be used as a means of communication. It is essential that energy cost will be seen as cost that can be actively managed. 3) Property managers are recommended to financially assess interventions in the scope of total maintenance expenditures so decisions are made in the complete perspective. For consultancy companies there is a role to support organisations in overcoming practical barriers to realise the exploitation of opportunities within building maintenance and provide tailor-made advice. More important, this research pledges advisory companies to adopt a proactive role in providing insight to clients on benefits and drawbacks of improving energy efficiency and finding tailor-made solutions. Lastly, concerning legislation on energy reduction, government is advised to focus on eliminating barriers and obliging actions that contribute to seizing saving opportunities such as perceiving insight in energy consumption.

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List of abbreviations

BMR	Building Maintenance and Repair
BOM	Building Operation Management
CT	Carbon Trust
CREM	Corporate Real Estate Management
DCF	Discounted Cash Flow
EI	Energy Index
ENPI	Energy Performance Indicator
EMS	Energy Management System
EPA-U	Dutch: Energie Prestatie Advies Utiliteitsbouw
EU	European Union
GHGE	Greenhouse gas emission
HVAC	Heating Ventilating Air Conditioning
KENWIB	Dutch: Kenniscluster Energie Neutraal Wonen en Werken in Brabant
KPI	Key Performance Indicator
LCA	Lifecycle Analysis
LCC	Lifecycle Costing
MCA	Monte Carlo Analysis
NEN	Dutch: Nederlandse Norm
NPV	Net Present Value
SD	System Dynamics

1. Introduction

1.1. Research context

At this moment over seven billion people are living on our planet. This number will continue to grow rapidly in the next decades. The population is consuming more and more energy (i.e. electricity and gas) which results in air pollution and global warming because of the emission of gases (mainly carbon dioxide) it goes accompanied by. International research indicates that reducing energy consumption and consequently Greenhouse Gas Emission (GHGE) is vital in mitigating climate change (Stern 2006; Metz et al. 2007). Worldwide, several agreements have been signed, such as the Kyoto Protocol (United Nations 1998), the Copenhagen Accord (United Nations 2009) and the 20-20-20 climate objectives (Commission of the European Communities 2007), with the intention to change the use of energy and reduce carbon emission. The European Union (EU) Member States agreed, as a part of the 20-20-20 targets, on reducing the total EU carbon emission with 20% (based on the 1990 carbon emission level) in 2020 and on the long-term goal of becoming almost completely carbon neutral in 2050.

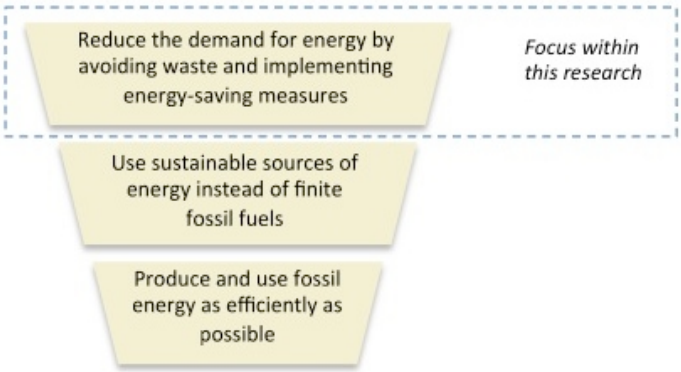


Figure 1.1 – Trias Energetica (Cees Duijvestein via Agentschap NL 2012)

The Trias Energetica strategy aligns with the 20-20-20 objectives, reducing carbon emission by reducing the demand for energy is the first and vital part of this strategy. The latest Reference Outlook (d.d. 2012) shows that with current policies, savings in the Netherlands are lagging behind and the 20% saving objective might not be achieved (Verdonk & Wetzels 2012). Especially within the non-residential built environment, which accounts for a large part of the carbon emission but the priority for energy reduction is still low, finding feasible solutions to achieve energy reduction is of vital importance. Societal attention for sustainability and energy reduction is growing and one of the possible improvement areas is within maintenance activities of corporate property. Therefore, this research focuses on how attention for energy performance within maintenance activities in the non-residential existing building stock can contribute to achieving the carbon reduction targets.

The research is performed as a part of the KENWIB project (Kenniscluster Energie Neutraal Wonen en Werken in Brabant). The research is supported by an internship within the advisory group Asset Management of the consultancy and engineering firm Royal HaskoningDHV (more information about the graduation company can be found in Appendix 1).

1.2. Problem analysis

The following problem analysis is founded by literature research and empirical research retrieved by expert interviews within Royal HaskoningDHV. The problem analysis focuses on the exploitation of energy reduction opportunities within the built environment with the aim to determine the problem statement for this research.

1.2.1. Energy reduction potential in the built environment

The built environment accounts for a major part of the carbon emission. Building activities such as development and demolishment contribute to carbon emission, e.g. transportation, production of materials, but the largest part of energy use results from buildings that are in use. Globally, buildings contribute between 20% and 40% to energy consumption in developed countries (Pérez-Lombard et al. 2008). In the Netherlands, the energy use concerning the built environment counts for approximately 30% of the total use of primary energy resources (Ministry of the Interior and Kingdom Relations, 2011). Although reports differ on what part of the total carbon emission is caused by the built environment, percentages vary between 10-30%. Dutch government aims at a substantial gain of savings in this sector (Agentschap NL 2011a). Considering that the existing built environment uses a great amount of energy, the question arises whether this also implies the presence of an energy saving potential. Research concludes that the biggest percentage of results can be achieved by improving the energy performance of our existing domestic and non-domestic buildings (Dobbs et al. 2012; United Nations Environment Programme (UNEP) 2009; European Commission 2011).

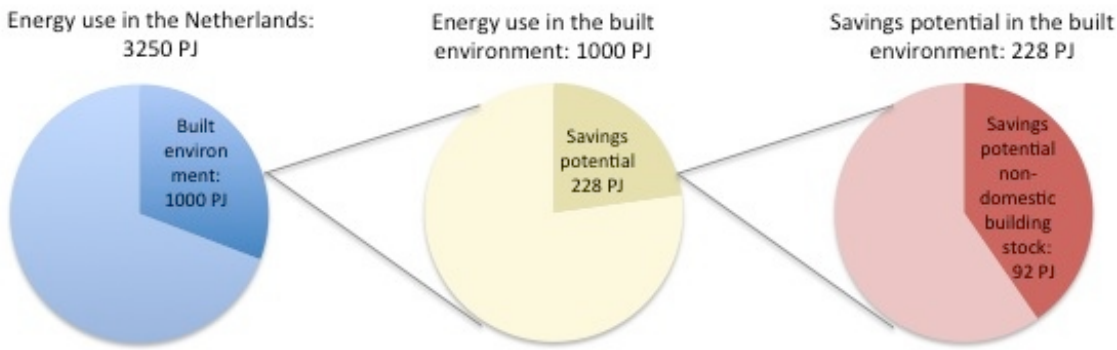


Figure 1.2 – Energy use of the built environment in the Netherlands and the technical saving potential (adapted from Planbureau voor de Leefomgeving 2012; Daniels & Farla 2006; Menkveld & Van Den Wijngaart 2007)

A potential saving in the Netherlands within the building stock amounts to 228 PJ (Daniels & Farla 2006) of which 92 PJ in the non-domestic building stock (Menkveld & Van Den Wijngaart 2007; Schneider & Steenbergen 2010). In the Netherlands 3250 PJ energy was used in 2011 of which approximately 1000 PJ in our built environment (Planbureau voor de Leefomgeving (PBL) 2012) what means that the energy saving potential for the non-residential building is 9% of all the energy used in the Dutch built environment and 3% of the total energy used in the Netherlands. Figure 1.2 visualises these proportions. The saving potential implies an enormous financial saving potential and raises the question why this technical saving potential is not exploited if the possibility exists that it can be translated into financial gains (Rooijers et al. 2010).

The potential financial gains that go accompanied with energy savings imply that there is a valid reason for property owners to improve the energy efficiency; any organisation that does not take full advantage of the profitable energy efficient building improvement opportunities will not survive in the present highly competitive economy (Kulakowski 1999). However, the potential is not exploited, which implies that there must be other (hidden) reasons that keep these companies from making the improvements. This was already stated in literature more than a decade ago and is also called the energy paradox (Jaffe & Stavins 1994b; Kulakowski 1999). The term paradox is applicable considering that a high savings potential against a low rate of adoption seems contradicting. However, there definitely are causes and explanations for this contradiction.

Firstly, the potential gain described in literature and put forward by government is not perceived as such by property owning organisations. Whereas energy savings in the residential sector represent a considerable part of total exploitation cost, for non-residential buildings this economic incentive is mostly absent. The savings that can be made consist of a very low percentage of total business cost of the organisations that own the buildings. Counterintuitive this means that there is no strong economic incentive to improve the energy efficiency of property (Kulakowski 1999; Högberg 2011). For example, while the potential energy savings in the non-residential market are 21% (in the United Kingdom) (Carbon Trust 2010) and thus represent a large potential cost saving, for a single office organisation the total energy costs are typically less than one per cent of the running costs (Junnila 2007). This means that no business risk is taken when ignoring these potential cost savings. Secondly, apart from the size of the potential financial gain, the effort required to realise the potential savings is high. Mainly, investment is necessary to implement interventions; for example human resources are required to examine which interventions should be implemented and money is required to pay for saving measures. On top of this, in the process of implementing interventions several barriers are faced such as lack of knowledge and uncertainty on cost that further limit the willingness of organisations to pay attention to energy conservation. This means that the hypothetic net value of the potential financial gains together with the effort and barriers to realise these gains result in an unprofitable scenario (Jaffe & Stavins 1994b). Note that due to the future energy prices are expected to rise the financial incentive to pay attention to energy efficiency might strengthen (Marino et al. 2011; Schneider & Steenbergen 2010), however, the barriers to realise the energy reduction remain.

The government tries to stimulate energy reduction by limiting barriers (e.g. limiting financial barriers by providing subsidies or tax refunds) and by legal obligations. Currently, besides fiscal advantages, mainly two regulations are applicable to energy reduction of the existing non-residential building stock. These Dutch rules are based on the EU Energy Performance of Buildings Directive (EPBD). Firstly, all the companies who are expected to be compliant to the Environmental Permit (Dutch: Milieuwet) and use more than 50,000 kWh electricity or more than 25,000m^3 are obligated to implement all energy efficiency improvements with a payback time less than five years. Recent research shows that a part of these organisations are not aware of this regulation and only 27% is (almost) compliant with the rule (Bakker et al. 2012). Secondly, since 2008, property owners are obligated to show the Energy Label from a building when selling, renting out or largely renovating a property. However, apart from a minimum required energy performance when refurbishing existing property, the Energy Label does not require any interventions. This means that there is a limited number of legal obligations subject to non-residential property that is not even fully effective. From a governmental point of view this means that either enforcement should tighten, policy needs to be strengthened or more effective solutions need to be found.

1.2.2. Improvement opportunities within building maintenance and repair

Experts in the field of property management notice unexploited opportunities for energy efficiency improvements in building maintenance activities (Royal HaskoningDHV 2012; Agentschap NL 2010). During the moments of relative quietness where only smaller maintenance activities take place in the lifecycle of a building there is a lack of attention for decisions regarding sustainability and energy efficiency (Agentschap NL 2010). With little extra investment of resources (e.g. time, knowledge or money) an intervention in a building might be possible that not only enhances the technical performance of the building but also contributes to energy reduction.

The reason why the opportunities to improve energy efficiency are not seized can be attributed largely to the lack of attention for energy performance. Analysing why this lack of attention within maintenance activities is present, shows that it is partially caused by energy consumption being a means to reach specific goals such as a comfortable environment (Aune et al. 2009). This results in energy use not being actively managed but treated as an expense item. Besides this, the overall lack of incentives for energy reduction in organisations strengthens this perspective. These above mentioned causes relate to the important issue that within the main purpose of traditional maintenance management there is no room for the improvement of energy performance; the objective is preserving (functional) property performance. Because improvement of the energy performance is not subject to preserving the performance, the associated costs are not seen as maintenance expenses but as an investment and investment decisions are not part of maintenance management (De Kopgroep Maatschappelijk Vastgoed 2008). Without a change in strategic objective, there is no foundation for the exploitation of improvement opportunities within building maintenance.

However, besides the lack of attention for energy efficiency within building maintenance, there are more reasons that clarify why opportunities stay unexploited. For example, organisations do not have insight in their real estate property energy consumption which causes opportunities not being identified. Besides that, organisation lack specific knowledge on how to seize opportunities (Schleich 2009; Yik et al. 2002). This knowledge for example concerns new technology or relates to financing methods. On top of all, understanding what the effects of exploiting the opportunities within building maintenance could lead to are unknown and difficult to assess. Without knowing how to take advantage of opportunities and what the results of this may be, organisations lack incentive to pay attention to energy efficiency within building maintenance activities.

1.2.3. Summary

Considering the need for solutions that help in reducing energy consumption of buildings, research into whether the attention for energy performance leading to exploiting energy efficiency improvement opportunities can result in energy reduction is of high relevance. Although the potential financial gain might be low for organisations, especially in the current difficult economic situation it is of interest to examine whether financial gains can be realised cost effectively. Embedding the improvement of energy efficiency in maintenance activities can be a way to focus on energy performance within daily existing processes. It is for good reasons that Agentschap NL promotes the adoption of energy performance improving measures within maintenance activities. However, practical barriers still need to be overcome and organisations need tools that help perceiving insight in the results of improvement measures. If can be examined how seizing opportunities within maintenance activities can be realised and how organisations can easily assess whether and how this leads to benefits, organisations might feel a stronger incentive to change the maintenance objective and to start exploiting opportunities.

2. Research approach

2.1. Problem statement

Saving energy and accordingly lowering carbon emission is a vital part of achieving the societal climate objectives and preserving earth. Especially in the existing stock of non-residential buildings there is a large technical potential to reduce the energy consumption. However, particularly because of a lack of commitment due to low financial incentives and high-required effort in the implementation process in which also multiple barriers are present, organisations refrain from implementing energy saving interventions. Although besides financial incentives other more qualitative incentives arise and thus the willingness to act increases, there are still not sufficient solutions provided to utilise the saving potential.

The consultancy and engineering firm Royal HaskoningDHV notices a substantial potential within building maintenance activities to save energy consumption of property. By smarter managerial decision making preventative maintenance or replacement of service systems and building elements can, besides preserving the functional performance, improve the energy efficiency of the building. Consequently, besides saving energy and lowering carbon emission other benefits can occur such as improved company image and a better indoor environmental quality.

> Within the boundaries of this research and based on the problem analysis the research problem can be stated as:
>
> "there are unexploited opportunities to decrease energy consumption within the maintenance activities of existing non-residential property"

The current organisational context of maintaining buildings does not allow a side-focus on energy performance due to the traditional maintenance objective to preserve the functional property performance what excludes the improvement of any type of performance (i.e. also energy performance). Besides that, multiple other barriers are faced when aiming to seize improvement opportunities. Without finding solutions on how to identify opportunities and assess the results of improvement measures, organisation lack insight, know-how and incentives to include energy performance objectives within property maintenance strategies. Knowing that the research problem is present in an environment where energy conservation is of high importance and solutions that contribute to this conservation are necessary, plus that paying attention to energy efficiency possibly increases the performance of the organisation together represent the relevance of finding a solution to this problem.

2.2. Research perspective

The research perspective is determined by practical, scientific and personal factors. For this research, contributing to finding a solution to the problem is approached from the perspective of organisations that manage property as a corporate asset. This means that the property and organisations subject of this research is non-residential real estate, which includes all non-domestic properties such as municipal buildings, property of educational institutions, financial institutions and retail. For these organisations, energy reduction is becoming more important due to increased insight in the benefits, however still they lack a financial incentive and feasible solutions. A useful other perspective would be the perspective of the government, considering that government is responsible for the climate objectives mentioned and designs instruments that are meant to stimulate organisations. However, the organisations will in the end have to act. Therefore, it will benefit society to a larger extent when organisations are able to address the societal problem without being forced or stimulated to by the government. From Royal HaskoningDHV's perspective this is also important; the clients of Asset Management are the types of organisations that (on term) seek for solutions. The consulting firm is increasingly facing questions relating sustainability and energy reduction and notice the presence of practical hurdles. Research from the perspective of their clients is therefore very useful from Royal HaskoningDHV's perspective.

2.3. Research objective

The main objective of this research is to contribute to solving the problem of unexploited opportunities within building maintenance activities what can lead to energy savings. Ideally, solving this problem should contribute to climate control while benefiting organisations by showing how a focus on energy performance within building maintenance can be effectuated (see Figure 2.1).

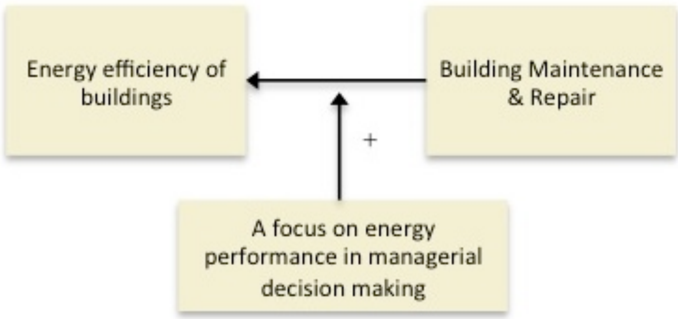


Figure 2.1 – Visualisation of the desired situation to which the research tries to contribute

This objective is pursued by (i) determining how maintenance activities can contribute to energy efficiency, by (ii) examining what procedures are possible to identify and assess opportunities and by (iii) developing a tool that helps assessing improvement opportunities.

2.4. Research questions

The research question and the sub-questions are described below and are based on the context, problem analysis, research perspective and research objective.

> *How can the opportunities to improve energy efficiency within maintenance activities of existing non-residential property be exploited?*
>
> RQ1: How can building maintenance & repair activities improve property energy efficiency?
>
> RQ2: How can energy efficiency improvement opportunities be identified?
>
> RQ3: How can identified improvement opportunities be assessed?

2.5. Research context and boundaries

As a support to the clarity of the research, the research context and the research focus is visualised in Figure 2.2. The figure shows that building energy efficiency should be seen as one of the elements of sustaining organisations and managing maintenance activities (i.e. Building Maintenance and Repair) as one of the secondary activities performed in an organisation. This context is further elaborated in chapter 3.

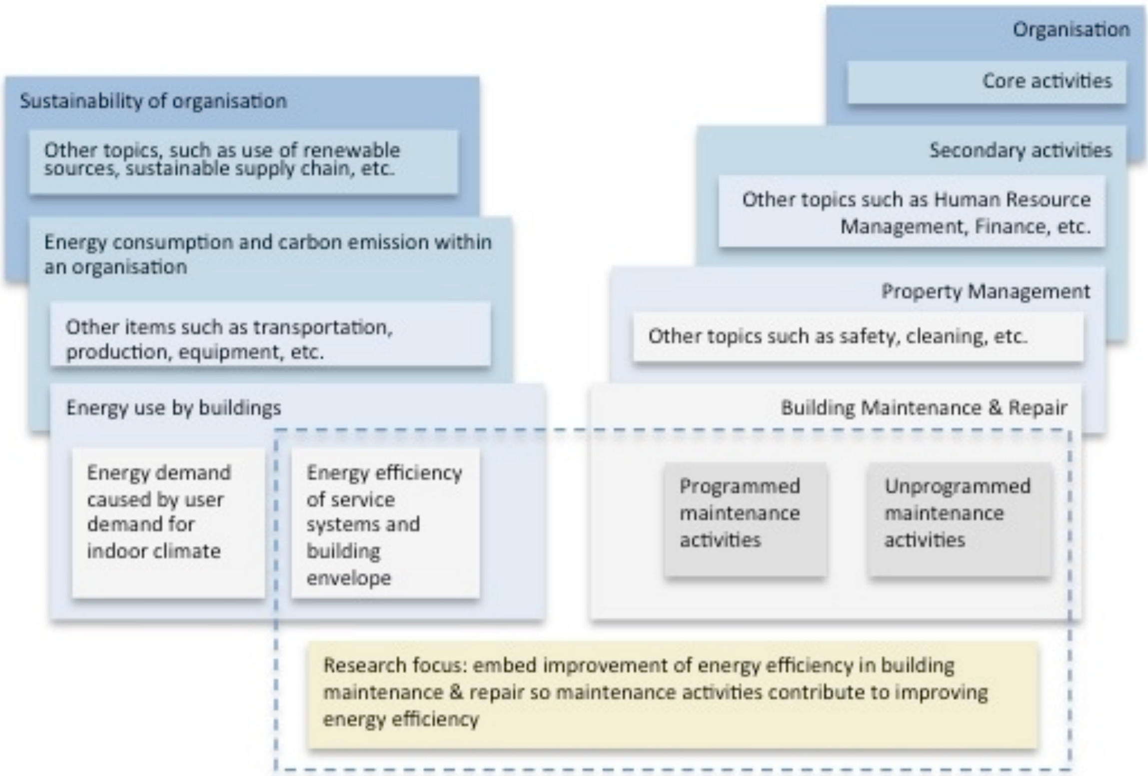


Figure 2.2 – Research focus in its context

2.6. Research methods

2.6.1. Development of the research design

This research aims to provide knowledge and information resulting in outcomes that can contribute to change an existing situation. Therefore, it can be defined as practice and design-oriented research (Doorewaard & Verschuren 2010). For this research there is no specific problem specified that aims to be solved but the practitioner is dealing with an unstructured set of problems. Therefore, an important part of the research is to provide knowledge by exploring the research topic and consequently formulating the specific problem that will be addressed including the appropriate research questions. The results of this part are elaborated in the first chapter of this paper and comprises the introduction of the further research. This part of the research can be placed in the light of the 'set of problems' and 'problem choice' of the regulative cycle developed by Van Strien as visualised in Figure 2.3. The 'diagnosis' and 'plan' phase consist of the actual research and design of solutions. Implementation and evaluation of these solutions are not part of this research, although the case study can be seen as a test phase concerning implementation and evaluation.

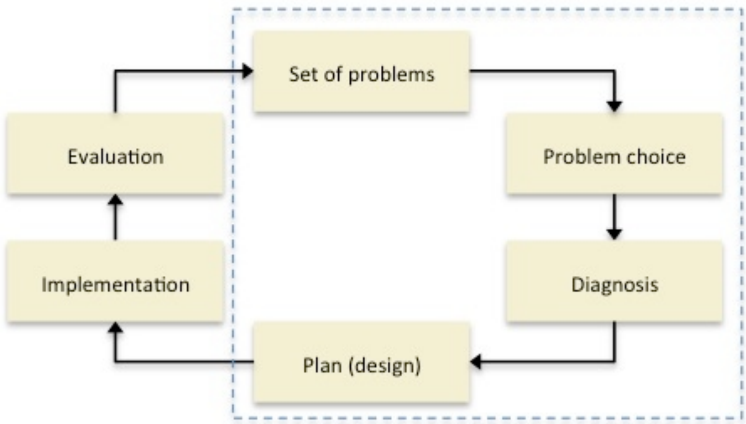


Figure 2.3 – The regulative cycle (Van Strien 1997)

2.6.2. Data collection

Literature review

Extensive literature review has been carried out to provide knowledge on and data within the areas of property management and energy management, aiming to find information to answer the research questions. Journals and magazines in the fields of facilities management, real estate management, environmental management, energy policy, energy economics and the built environment where reviewed to select articles that cover the required topics by searching using keywords and by snowballing. The reliability of the literature differs due to different backgrounds and different types of journals. The relevance was examined by preselection. Only papers that are part of the research scope were assessed (i.e. non-residential property, corporate property, energy management of buildings, developed countries). To address the concerns on reliability, multiple resources are used on the different research topics and field experts were consulted to validate information.

Expert interviews

Interviews with employees of Royal HaskoningDHV have been instrumental in supporting the scientific knowledge gained from literature with empirical knowledge. Experts within the field of Asset Management, Building Services and Building Physics have contributed to developing well-founded conclusions on both scientific as empirical information. Besides this, these experts have broad knowledge about characteristics of market actors and market trends. Because the ideas and practices described in literature differ from practice in the Dutch property market, expert input contributed to a large extent to the relevance of this research. The types of interviews are exploratory to build the research context and analyse the problems. Besides that, interviews were conducted with civil servants within the maintenance department of the municipalities of Nijmegen, 's Hertogenbosch and Eindhoven to verify the assessment tool and case study results.

2.6.3. System Dynamics and Monte Carlo Analysis

System Dynamics (SD) is a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems and is used in this research to develop a tool that aids decision-making. SD is applied in this research as the main methodology in developing an assessment tool that support the decision making process by modelling future effects. Modelling future behaviour is inevitably linked to making assumptions; these assumptions can be wrong. Therefore, testing the effects of deviant behaviour regarding the modelling results and conclusions is important. This process is in this research lead by Monte Carlo Analysis that enables simulating multiple scenarios and combining the outcome into an overview on possible outcome differences due to uncertainty. More information about the two methodologies is elaborated in paragraph 5.2 and 5.4.3.

2.6.4. Case study

Descriptive case study

A case study is performed 1) to verify the dynamic assessment tool and 2) to analyse how for the specific case the effects are influencing the organisational performance. A critique on using case studies in research is that results are difficult or cannot be generalized (Hertzsch et al. 2012). As such, the goal of the case study in this research is to verify the use of the model and to test for this specific case what the effects are when implementing improvement opportunities. This means that the results regarding the assessment cannot be generalised.

Case selection

One case study was performed due to limited time availability. The municipality of Nijmegen was chosen as a case for this research for the following reasons. Firstly, relatively much information on the building portfolio, that is necessary to use as input, is available. This is due to Royal HaskoningDHV being the managing agent of the real estate portfolio, which enables access to building information and information on possible energy efficiency improvements. Secondly, for municipalities, improving the efficiency of their real estate portfolio is becoming more urgent. The selected case for this research is the City Hall; this building can be seen as a flagship of the municipality because of its public function.

2.7. Research framework and report outline

Following the research framework in which the elements of this paper and the research methods are visualised.

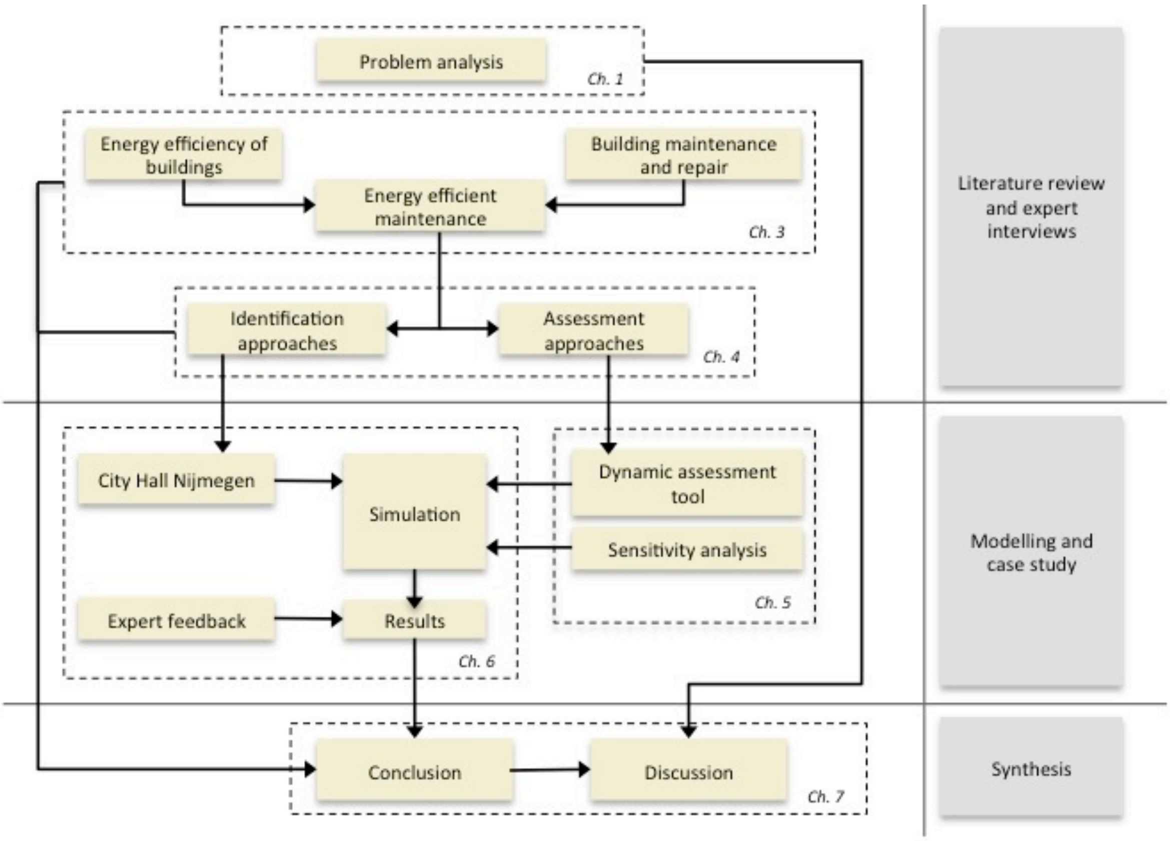


Figure 2.4 – Research framework

This research paper consists of seven chapters, of which this paragraph concludes the explanation on the research approach that was preceded by the research context and problem analysis (chapter 1). Chapter 3 elaborates on the main topics and provides information to answer research sub-question 1. In chapter 4 the literature review and expert interviews on energy management is combined with literature on decision-support tools concerning the process to exploit improvement opportunities within maintenance management, focusing on the identification and assessment phase. Chapter 5 introduces a dynamic assessment tool that helps to assess the effects of energy efficient maintenance activities. A case study, described in chapter 6, focused on identifying and assessing improvement opportunities using the assessment tool for the Nijmegen City Hall case. The findings of the research are given in chapter 7 including an extensive discussion and recommendations for further research.

3. Energy efficient property maintenance

This chapter elaborates on the two main concepts of this research: energy efficiency within corporate property and property maintenance. The two concepts are synthesised in paragraph 3.3.

3.1. Improvement of building energy efficiency

3.1.1. Energy efficiency of buildings

Within organisations, buildings are only one of the energy-using elements, primarily by creating heat and cold out of electricity and gas. Depending on the core business of the organisation, also for example transportation, production and office devices such as computers and printers consume energy. The use of energy results in carbon emission either because carbon dioxide is emitted during the production of energy (e.g. electricity in coal plants) or by direct combustion of gas (e.g. in a boiler) (Menkveld & Van Den Wijngaart 2007). Controlling carbon emission is therefore inextricably linked to controlling energy use. The set of activities and procedures to do so is referred to as energy management. Agentschap NL, the division of the Dutch Ministry of Economic Affairs that support sustainability, innovation and international development, defines energy management as the implementation of organisational, technical and behavioural measures that minimise the energy use, in a structural and economic responsible manner (Agentschap NL, 2011). Several energy management systems (EMS's) are developed to help organisations developing sound energy management. A management system is a set of activities and procedures that an organisation needs to follow in order to meet its objectives (ISO 2013). More information on two energy management systems (i.e. Carbon Trust and NEN) can be found in Appendix 2.

The energy consumed 'by' buildings is used by the service systems primarily for heating, ventilating and air-conditioning (HVAC), and lighting. However, the specific use of energy of these systems is influenced by various factors. For example, the insulation capacity of the building envelope determines the heat (or cold) losses what can result in the heating system to use more energy to reach the desired indoor temperature. Besides the insulation capacity of the building envelope also human behaviour influences the energy consumption; the users or operators determine the intensity of energy use by for example turning on the heating or lighting. Besides this, the technical characteristics of a system influence the energy use; a heating system 30 years of age produces less heat out of the same amount of gas then a system one year of age due to a different heating yield and deterioration. The situations described above (i.e. low insulation capacity of the building envelope, unnecessary operating time, and old technology) are examples of a building's energy inefficiency; efficient means functioning in the best possible manner with the least effort (Van Dale Dutch dictionary) or productive without waste (Merriam-Webster dictionary). Energy efficient can be defined as functioning in the best possible manner with the least use and/or without loss of energy.

3.1.2. Energy efficiency improving measures

Improving the energy efficiency of a building means that interventions are required that affect the energy performance of the property. It is of importance to understand that the possible improvements are not a 'shopping list' where a implementing as many measures as possible is the most effective. Rather a balanced combination of interventions will maximise the energy reduction with the minimum of technologies (Hertzsch et al. 2012). Choosing specific interventions is highly dependent on the characteristics of the building and the functional demand resulting from the building users. Besides this, note that multiple 'interventions' are no incidental improvements but rather are part of continuous energy management. Considering that a building is subject to changing circumstances and deterioration, one should not forget that energy efficiency will decrease over time and improvement measures should be recurrent. The possible measures aiming at improvement of the energy efficiency of a building can be subdivided into three areas: organisational, technical and architectural (Junghans 2013).

Organisational measures target usage and operational activities. This type of measures does not relate to the technical-functional aspects of a building. User behaviour but also the intensity and duration of use of a building is of interest when it comes to the organisational perspective. Improvements from this perspective contain for example improving the user awareness of turning of lighting, but can also relate to effective scheduling of evening activities what for example leads to a part of the building not requiring heating. Research on end-user effects on energy conservation in offices consisting of a case study into four banking organisations in Scandinavia (size 160,000-270,000 net m^2 and built before 1990), shows a potential overall electricity consumption saving of 20% (Junnila 2007). Because interventions on organisational level highly relate to organisational culture and communication, and do not directly relate to building energy efficiency, this type of interventions are left out of the scope of this research. However, end-user management definitely can contribute to energy saving and should therefore not be forgotten by any organisation pursuing energy reduction.

All the technical utilities, or most often named service systems, comprise the direct energy consumers and are main causes of energy inefficiency. Old or malfunctioning machines either require an upgrade by maintenance or overhaul, or replacement to improve for example the heating or cooling yield. Besides this, building systems are often faced with unexpected user actions or 'sabotage' (Aune et al. 2009) what results in not optimal functioning of these installations. Also preventative maintenance activities can suboptimise the energy performance. Therefore, optimising the technical or user settings of the systems is one of the areas of energy efficiency improvement and is referred to as retrocommissioning or continuous commissioning. Retrocommissioning seeks to ensure the functionality of equipment and systems and also to optimise how they operate together in order to reduce energy waste and improve building operation and comfort (Haasl & Sharp 1999). An example of retrocommissioning climate systems is the Rijksgebouwendienst, who systematically optimises the service systems of their properties (Dutch: Functioneel Controleren, Inregelen en Beproeven van de klimaatinstallaties (FBIC) (Rijksgebouwendienst (RGD) 2010). Whereas retrocommissioning is often incidental, continuous commissioning has the key goal to ensure that building systems remain optimised. To achieve this, continuous commissioning requires benchmarking pre- and post-energy use via smart-metering equipment that is permanently installed. Continuous monitoring and adjusting service systems where necessary, can lead to 10-25% energy savings (Gemeente Amsterdam 2011; Rijksgebouwendienst (RGD) 2010). Other energy efficiency improving measures regarding the service systems relate to heat, cold and steam recovery and to the type of energy sources (Hertzsch et al. 2012).

Service systems	
Main elements	**Activity**
Boiler Air Handling Unit (Dutch: Luchtbehandelingskast (LBK)) Air-conditioning Unit Waste Heat Heating System (Dutch: Warmteterugwinning (WTW) Elevators Lighting system	Retro-commissioning Continuous monitoring and commissioning Insulation of components Upgrade/overhaul (Re)placement
Building construction elements	
Elements	**Activity**
Facade Roof Foundation Floor Indoor walls incl. doors Glazing Other	Insulation, sealing air leaks Replacement of elements to materials with increased thermal resistance, external reflective surfaces (light colours) Placement of new elements: blinds, curtains, buffer zone entrance/enclosed porch, door closers, green roof Incidence of daylight, type of glazing Link to organisational and technical: motion detector controlled lighting, thermostatic temperature control, zoning

Figure 3.1 – Possible energy efficiency interventions regarding service systems and building construction elements (Junghans 2013; DHV 2011; Agentschap NL 2010; Junnila 2007)

From an architectural perspective the improvements relate to the building construction and mainly to improvement of the thermal resistance of the building envelope. Interventions in the building construction (e.g. roof, floor, façade) can be replacement of elements (e.g. window frames), but also the placement of insulation or other performance improving events such as changing the use of daylight and shading (Hertzsch et al. 2012). Note that regardless the efficiency of the service systems, due to low energy performance of the building envelope the total property energy efficiency will be low. An overview of possible technical and architectural interventions can be found above in Figure 3.1.

3.2. Maintenance of corporate property

3.2.1. Corporate property management

Property can be held either as an investment asset or as an operational asset (Edwards & Ellison 2008). Buildings held as an investment asset are seen as investment and thus expected to earn a certain rate of return. Property held as an operational asset has the aim to support the activities of the organisation that owns the property; this is the type of property this paper focuses on and is often referred to as Corporate Real Estate. Whether a property is held solely for investment purpose or as an operational asset, strategic management of property is crucial in ensuring that the property is managed for maximum value (Edwards & Ellison 2008). There should be considered that with or without issues of sustainability or of any other context, making decisions about real estate assets are already complex because they are technical artefacts made up of many components with different characteristics (Hertzsch, Heywood, & Piechowski, 2012). Besides that, for operational property, property management decisions are constrained in that the primary purpose of owning or renting the property is to enable the fulfilment of functions other than pure financial return on the property (Avis et al. 1990). This means that managing property is also constrained by other decisions; think of business decisions such as closing a department what results in property redundancy. Although these other topics are out of scope of this research, when reflecting on the result of this study, these factors should be taken into account.

Corporate Real Estate Management (CREM) focuses on property owned by organisations that are not primarily in the real estate business (Hiang & Ooi 2000). The elements of this type of management are shown in Figure 3.2. On a strategic level, CREM covers the entire range of activities concerning portfolios of buildings and land holdings: investment planning and management, financial planning and management, construction planning and management, and facilities planning and management (Hiang & Ooi 2000).

Figure 3.2 – The domain of Corporate Real Estate Management (Bon et al. 1994)

Management of a property on a tactical level consist of multiple services and activities sheltered within Facilities Management (FM). FM is tactical and operational oriented and includes services related to aspects that facilitate an organization and its users. These services that can be provided by either an in-house department or by companies under contract (Shah 2007). Typical topics that are of concern for the facility manager are catering, security, secretarial services and also facility or property maintenance. Where FM focuses on planning of the activities relating to these services, on a physical level the actual operations take place, such as for example cleaning of property or replacement of service systems. These activities are part of Building Operation Management (BOM). Property maintenance is one element within BOM and is organised within Building Maintenance and Repair or also called Maintenance Repair and Operations (Dutch: onderhoud en beheer).

3.2.2. Building maintenance and repair

Traditional building maintenance and repair (BMR) of corporate property focuses on preserving the condition of buildings; the building serves the organisations core objective and should comply with the required functional standard. To reach the objective, maintenance activities are performed that include replacement, preventative and corrective maintenance activities concerning technical and architectural elements of a building. Note that retrofitting, which are actions required to bring a building into the framework of new requirements due to for example a changing user (Alanne 2004), are not part of regular BMR. The basic principle in BMR is that every single element in a building has a service life after which it needs to be replaced. Preventative maintenance is performed to ensure the components actually achieve their service life (Stanford 2010). Activities concerning architectural elements are for example painting the window frames or the replacement of façade elements. Technical elements concern the service systems, for example cleaning the ventilating system or replacing an entire heating system. As a part of preventative maintenance, predictive maintenance uses routine inspection, testing and analysis to augment routine scheduled maintenance when problems are identified (Stanford 2010). Where replacement and preventative interventions are often planned, corrective maintenance is performed when an element suddenly malfunctions. The exact activity when performing corrective maintenance is often similar to activities performed by programmed maintenance as visualised in Figure 3.3.

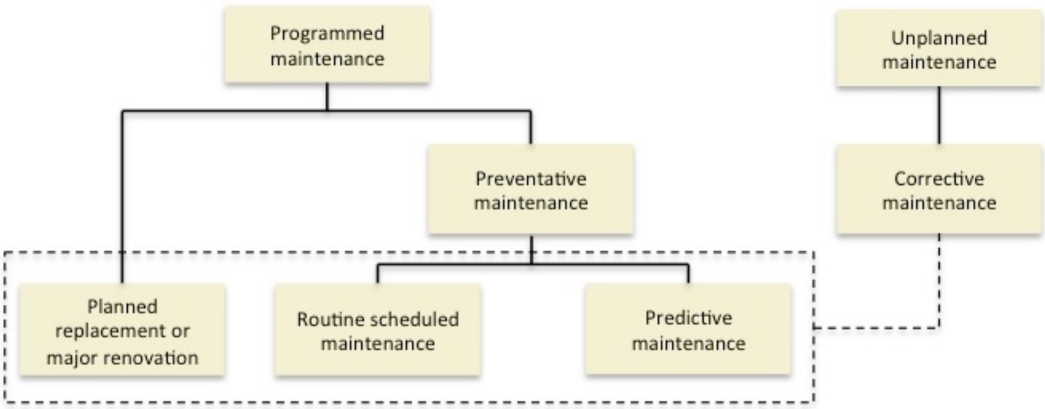


Figure 3.3 – Elements of programmed maintenance (adapted from Stanford 2010)

Programming maintenance is important by the principle of stewardship. Stewardship is an ethic that entails the responsible planning and management of resources. Because managing corporate real estate being a secondary activity within most businesses, sound stewardship is not always seen. Although property is an important asset that, if carefully managed, can contribute significantly to the broader goal of corporate survival (Mansfield 2009), in practice this mind set is not always present throughout the corporate property organisation. For example, BMR is expected to minimise expenses resulting in the postponing of maintenance, what might cause higher cost at later moments in time due to sudden failures. In this paper, we assume that the goal of property management is to provide maximum property value and thus active management and sound stewardship is present. This means that organisations ensure planning maintenance activities, allocate expenses and decide on what resources to spend on what moment in time, all with the goal to manage property for maximum value. Note that the cost of maintenance includes all cost of preserving the property during its lifecycle. For traditional maintenance it thus includes costs exclusively to maintain the technical situation of a property (De Kopgroep, 2008).

Within maintenance management, a distinction is made between operational and capital expenditures. Operational expenditures (opex) relate to preventative maintenance cost while capital expenditures (capex) relate to replacement; often a capital expenditure is not an expense but is translated into equity on the balance sheet because this is regulatory obligatory, yearly the value will be depreciated resulting in operational expenditure. This means that besides a technical lifetime, elements also have an economic lifetime; investments are depreciated over a certain amount of time and thus annually 'lose' value. The planning and financial budgeting of maintenance activities is in the Netherlands described in a multiyear maintenance plan (Dutch: MJOP; meerjaren onderhoudsplan en prognose). This plan shows the planned maintenance activities and the required resources on the long-term (Agentschap NL 2010). The use of Computerised Maintenance

Management Systems (CMMS) or Enterprise Asset Management Systems as a support to BMR is often seen in practice; information concerning property elements is included in these systems. For example, the condition of the element is visible, the age, and the scheduled or required activities for this element.

The Dutch BMR market revenue within the Real Estate sector accounted for 5.9 billion euro in 2012 (NVDO, 2013). In the Netherlands around 80% of the operational activities of maintenance management is outsourced to specialised contractors (Herik et al. 2013) mainly due to property management and thus maintenance management not being a part of the core business of an organisation. Outsourcing of maintenance activities can either mean that singularly the execution of maintenance work is outsourced, that the decision making on when to carry out maintenance is outsourced or even the organisational management is outsourced. The type of maintenance contracting that is seen within the Netherlands is shifting from effort to performance based; the contractor is rewarded for the achieved (or preserved) condition of the building instead of for the activities that are performed. Concerning energy reduction this shift is interesting because it enable the possibility to make agreements on maintaining or improving property energy performance. However, at this moment in time, performance contracting is mostly limited to the technical performance.

The actors responsible for the execution of building and maintenance management are often referred to as building operators. In the Netherlands, the lack of building operators is considered in 2012 as the most worrisome trend in the maintenance sector (NVDO, 2013). When practical maintenance work is outsourced, building operators within the organisation often have the main responsibility of administering the work (Aune, Berker, & Bye, 2008). This also indicates that the strategic and organisational or tactical aims and responsibilities of maintaining property is determined inside the organisation, whether the operational work is outsourced or not. A lack of (knowledgeable) building operators is therefore of crucial importance in guaranteeing that property is maintained for maximum value. Nowadays a shift is seen that besides outsourcing operational maintenance also the organisational or tactical management is outsourced. This means that in between the CREM organisation and the contractor a managing agent is present. This indicates that responsibility for sound maintenance management can lie out of the core organisation and the lack of in-house maintenance knowledge is less a problem.

3.3. Energy efficient building maintenance

In order to exploit opportunities within BMR to improve property energy efficiency, insight is required in how efficiency interventions can be covered within maintenance activities. When comparing the energy efficiency interventions mentioned in paragraph 3.1.2 to traditional maintenance activities, there can be seen that the same building systems and elements are subject to the performed activities. This indicates that within maintenance activities, indirectly the energy efficiency is influenced and thus a part of the opportunities are easily identifiable. The energy performance of the service systems can be influenced by preventative maintenance and by replacement. For example, preventative maintenance such as replacing a ventilation-filter in an air-handling unit as well as replacing an entire system (mostly positively) influences the energy efficiency. The energy performance of building elements is only influenced by replacement. Preventative maintenance does not influence the energy performance; for example painting does not influence the insulation capacity of a window frame, while the replacement of a window frame can influence the insulation capacity if the material of the new frame has a higher thermal resistance. This means that preventative maintenance of service systems can influence the energy efficiency, and replacement of service systems and building construction elements can influence the energy efficiency. The placement of new service systems or building elements are not part of traditional BMR, what means that this should become an additional focus of BMR. Insulation of elements can be seen as a part of placement of new elements. Retrocommissioning or continuous commissioning of service systems is also an activity that should be adopted.

	Preventative maintenance	Replacement	Placement
Service systems	✔ including retro- or continuous commissioning	✔	✔
Building envelope		✔	✔ including placement of insulation

Figure 3.4 – Synthesis of energy efficiency interventions within maintenance activities

The above figure shows that energy efficiency can be improved by maintaining property when (1) preventative maintenance of service systems and replacement of service systems and building envelope elements takes place, and if (2) placement of new elements, retro- or continuous commissioning of technical systems and insulating building elements are adopted within BMR activities. Note that unplanned or corrective maintenance is not mentioned in the figure; this type of maintenance often comprises the same activities as planned maintenance, although the decision what to do and when to do it, it made in place in stead of in advance. Especially the planned maintenance schedule offers a great opportunity to involve energy efficiency improving measures within the future maintenance activities (Agentschap NL 2010).

The previous paragraph described what activities should BMR entail to improve energy efficiency. These activities should only be performed if the energy efficiency can be improved, or if the functional performance of the building needs to be improved. Note that preventative maintenance and replacement activities are already part of BMR and are scheduled beforehand. Concerning the traditional focus, mainly four aspects need to change. 1) A focus on energy efficiency means that preventative maintenance of service systems is not only done to ensure a component will achieve its service life, but also to optimise its energy efficiency. Retro- or continuous commissioning is an additional activity that helps achieving this optimisation. 2) The scheduled replacement of elements traditionally is a one-for-one replacement, i.e. the element is replace with the same technology. However, energy efficient maintenance should focus on the energy efficient replacement possibility. 3) Within traditional BMR, replacement will take place when the technical lifetime of a component has ended. A focus on energy efficiency might lead to earlier replacement of elements because this is more (cost) efficiently than waiting until a components technical functioning has ended. 4) Placement of new systems or building components, including insulation, are additional activities that are not sheltered within traditional BMR. Ideally, the placement of new elements is combined with other maintenance activities so costs can be minimised. Summarised, these four aspects indicate that by energy management of service systems, earlier and improved replacement of components possibly combined with additional placement of energy efficiency improving elements, BMR can contribute to improvement of building energy efficiency.

3.4. Summary

This chapter elaborated on building energy efficiency, efficiency improvement measures, property management, building maintenance, and what activities building maintenance and repair should entail to embed efficiency improvement measures. Property energy efficiency can be defined as functioning in the best possible manner without waste of energy. Improvement of energy efficiency can be realised by implementing measures regarding the building service systems and building envelope with the aim to eliminate waste of energy. For corporate bodies, building maintenance and repair is a non-core business activity in which minimum effort is expected to realise the required functionality by conserving the technical performance of the property. Replacement of elements occurs when components' lifetime has ended, preventative maintenance is performed to ensure components achieve their expected lifetime. Building maintenance can improve property energy efficiency within existing maintenance activities (i.e. preventative maintenance of service systems and replacement of service systems and building elements) and by adopting new type of activities (i.e. commissioning, insulation and additional placement of elements). The table below compares the traditional BMR strategy with the energy efficient focused strategy.

Table 3.1 – Comparison of traditional and energy efficient building maintenance and repair

	Traditional BMR	Energy efficient BMR
Objective	Conservation of technical functionality	Conservation of technical functionality and optimisation of energy efficiency
Activities	• Preventative maintenance to ensure technical and economic lifetime of service systems and building components • One to one replacement of systems and components when technical lifetime has ended	• Preventative maintenance to ensure technical and economic lifetime of service systems and building components, and to optimise energy efficiency • Replacement of systems and components when or before technical lifetime has ended with energy efficient solution • Placement of new systems and components including insulation if this can improve energy efficiency

This chapter provided an overview on what type of activities should be sheltered within BMR to enable improvement of energy efficiency. Now it is of importance to understand how organisations can identify opportunities that can be translated into a maintenance activity, and consequently, how to assess these opportunities so a decision can be made on what measures to implement.

4. Approaches to identify and assess improvement opportunities

This chapter elaborates on what elements or steps need to and can be taken when identifying (paragraph 4.2) and assessing (paragraph 4.3) energy efficiency improvement opportunities within BMR. The previous chapter described for what type of maintenance activities positively affect energy efficiency. However, because every property has unique characteristics and different functional demands, finding the specific opportunities and exploiting these opportunities requires multiple steps. A procedure on how to identify and assess these opportunities is necessary before being able to make decisions on what interventions or maintenance activities to implement. First, the context of identification and assessment when it comes to exploiting opportunities is explained.

4.1. Introduction

The identification and assessment of possible improvement measures can be seen as a part of a larger process; more steps are required to turn opportunities into improved property energy efficiency. This procedural context is derived from resources in literature. Figure 4.1 shows the four main steps in exploiting energy efficiency opportunities followed by "evaluation and monitoring" that aims to assess implemented interventions and indicate the presence of (new) opportunities.

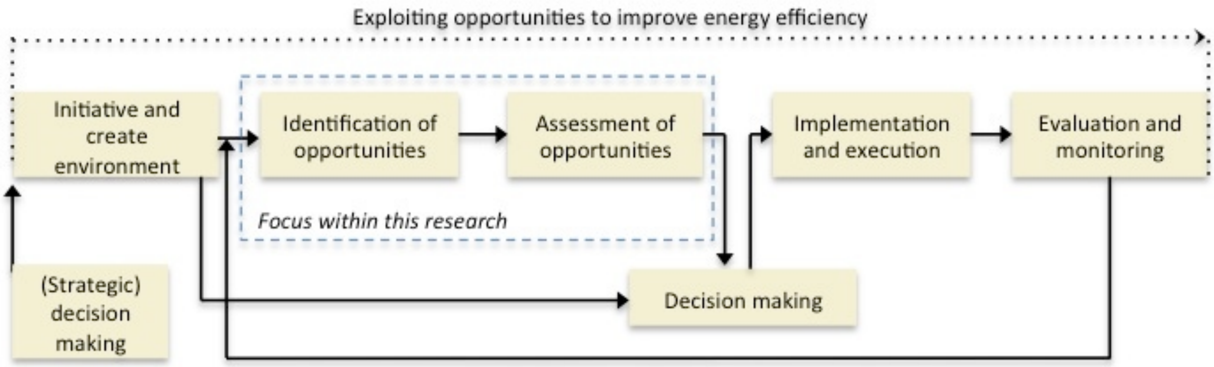


Figure 4.1 – The required steps to seize improvement opportunities

Within the initiative phase the environment is 'created' necessary to perform the next steps, think of setting of objectives, determining the exact identification, assessment and implementation procedure, and appointing responsible employees for each step. Note that multiple of these aspects contribute largely to the activity of making decisions about what measures to implement by for example framing the objectives the measures should contribute to. Note that a management decision is the catalyst for the procedure or process to start.

In the light of energy efficiency measures as a part of BMR, the above steps can be further specified. A guideline developed by Agentschap NL especially for municipalities to sustain their maintenance planning, describes eight steps: initiative, organisational exploration, development of possible scenarios, objective setting, development of business cases for specific scenarios, decision making, planning, execution and evaluation. These steps are translated in the structure of Figure 4.1 resulting in Table 4.1. Note that step four and five relate to the identification and assessment of opportunities.

Table 4.1 – Phases in the development of an energy efficient maintenance plan (adapted from (Agentschap NL 2013b)

Phase	Activities	Result
1 Initiative	Secure widespread support, assemble project team, select buildings	Intention
2 Organisational exploration	Develop project description, define legislative objectives and sustainability objectives, explore level of property information, explore financing possibilities	Definition of starting point
3 Objective setting	Define ambition level and objectives	Objective
4 Development of possible scenarios	Refine current maintenance plan, develop improvement scenarios complying with ambition level and objectives	Packages of measures / scenarios
5 Development of business cases for specific scenarios	Determine long-term effects of selected scenarios	Business cases
6 Decision making	Examine the scenarios according to organisational procedures, choose what scenario to follow, in cooperation with higher management	Scenario
7 Planning	Implement scenario in maintenance planning	New maintenance plan
8 Execution and evaluation	Realisation of the new maintenance plan	More energy efficient building

The importance of considering identification and assessment approaches is threefold. Firstly, buildings are complex systems in which many components are present and they are completely authentic; each property has specific technical characteristics, user demand, and is subject to specific environmental influences. This means that for every building other improvement opportunities are present within the field of energy efficiency what requires a case specific study. Identifying standardised ways or procedures can help in fastening and structuring the identification process. Secondly, as described in the research context and in the previous chapter, many barriers are faced in current processes that have the aim to improve energy efficiency. Therefore it is of importance to understand what barriers can be faced in the process when paying attention to energy efficiency within BMR. Thirdly, assessment of improvement possibilities is done in many ways and based on many criteria. This requires an overview of the different approaches including their pro's and con's. Consequently, the most useful or sound approach can be chosen.

Besides a focus on identification and assessment, briefly the barriers were reviewed that occur in other steps of the process. Following, two of these barriers that are considered of high importance:

Objectives, targets, Key Performance Indicators (KPI's) and Energy Performance Indicators (EnPI's)

Variables of which a specific value determines the desired performance of a business process are called KPI's and concerning energy performance EnPI's. Appendix 3 gives an overview and elaboration on multiple KPI's concerning buildings and its energy performance. Targeting and setting objectives can be done using these KPI's. Preferably the maintenance policy minimally includes targets concerning the energy performance and the technical performance of the property. The KPI's can be used by building operators to identify performance discrepancies, but can also help assessing improvement opportunities. One of the objectives should be to comply with legal obligations. Legislation on non-domestic existing property concerning energy performance is little, however, currently not even all organisations are compliant. Further information on legislation can be found in Appendix 4. Note that legislation concerns both topics of sustainability and property in general. The setting of objectives is widely mentioned in literature because it supports determining disconformities and so initiate the implementation of improvement measures.

Financing procedure

Improving the energy efficiency of an existing building requires organizational, technical and consequently financial resources. The required adoption costs to improve the energy efficiency are perceived as a barrier (Jaffe & Stavins 1994a; Yik et al. 2002; Högberg 2011). In the era of the financial crisis, property owners lack investment power and priority for secondary activities, especially in the case of property owners for whom investing in energy efficiency is not a core business and where these types of investment have to compete with core-business investments (Hiang & Ooi 2000; Högberg 2011). A case study analysis even concluded that energy efficiency projects have a different capital budgeting request procedure and faced a higher 'hurdle rate' than capital improvement projects of comparable risk (Kulakowski 1999). Ideally, in every organisation a procedure is developed that supports finding adequate funding. By embedding energy efficiency measures within maintenance activities, first of all the resources required might be lower, because the measures are only an increment to activities that are already planned. On top of this, an integral approach does not require priority on higher management level when it comes to capital budgeting what prevents energy efficiency investment losing out to other business investments. Note that this does implicate that within BMR budget is available to improve energy efficiency.

This paragraph gave insight in the entire process of implementing energy efficiency improvements within maintenance activities, highlighted two aspects of the first phase of the process and described the importance of focusing on the identification and assessment step. Therefore, following elaboration on these two aspects: identification approaches and opportunity assessment methods.

4.2. Identification approaches

This paragraph focuses on in what ways efficiency improvement opportunities can be identified that can be exploited within maintenance activities and what problems are faced in this process. Basically, opportunities are present when the actual energy efficiency is lower than the technical possible energy efficiency. Note that optimal energy efficiency is hard to define because it highly depends on the functional required performance. However, in this research energy efficient is determined as functioning to the desired level of the organisation without waste of energy. This indicates that identifying opportunities is concerned with identifying situations in which energy is wasted. Consequently, one or more solutions need to be found that can eliminate the waste of energy.

Identifying improvement opportunities consist of three elements: 1) identifying deviant behaviour or energy inefficiencies 2) identifying components responsible for energy inefficiency 3) finding solutions that can eliminate the inefficiency.

4.2.1. Identification of energy inefficiency

Energy inefficiency indicates that energy is wasted, in other words, a too high amount of energy is used. Obtaining insight in the energy performance of a property can therefore help to find inefficiencies. The energy performance can be measured by monitoring property energy use by installing energy meters. Possibly, the information given by these meters can be connected to Building Management Systems (BMS's) that gathers management information on the property. Benchmarks can be used to consider whether the energy consumption differs from properties with the same characteristics. Without comparable energy information, it is hard to identify if improvement is possible (Schleich 2009; Yik et al. 2002; Carbon Trust 2010). For example, SenterNovem publicates average energy use per m^2 for multiple real estate functions (SenterNovem 2013a), and other benchmarks mention energy costs as part of facility cost such as NFC Index (NFC Index 2013). Unfortunately, many organisations are unaware of the energy performance of their building because they lack insight in energy consumption. The lack of insight in energy specific performance means that many possibilities for the reduction of heavily energy intensive energy consuming practices are left unknown (Crosbie et al. 2010). This makes measuring efficiency of existing buildings an essential step in improving energy efficiency. "You cannot manage what you do not measure" (Carbon Trust 2010).

The above focuses on energy performance on property level. However, real time monitoring the energy performance of individual or a combination of service systems can indicate inefficiencies that are difficult to find by an invoice check or annual energy use. For example, if can be seen that a boiling system is using a lot of gas in the middle of the summer, this might indicate wrong settings or another flaw in the system. Without monitoring the energy performance, these types of nonconformities stay unknown and energy is wasted consistently. Continuous monitoring is a part of continuous commissioning as described in paragraph 3.1.2. Ideally, monitoring is part of preventative maintenance, however, in practice it is not often seen within organisations because it requires specific software and knowledge. Although BMS's do register specifics such as room temperature and moist level, they often do not register the energy use by the service systems. Specialised energy consultants offer monitoring services to assess the above.

Another way to identify energy inefficiency is to evaluate standardised energy performance indicators such as the Energy Label. For example, property with Energy Label G most likely has energy inefficiencies. However, Energy Label A does not directly indicate that property is energy efficient, because the Energy Label is highly influenced by the presence of renewable sources as well. Another party that can help indicating improvement opportunities is the occupant; they have a good view on the current state of the building (Strachan & Banfill 2012).

4.2.2. Identification of energy inefficient components

If deviant energy consuming behaviour is recognised, the source that is causing the unusual behaviour needs to be found before specific improvement measures can be identified. Note that without having insight in the energy performance, the identification of underperforming components can also take place.

Just like the identification of technical performance, energy performance can be identified by the use of an inspection methodology. In the Netherlands, the NEN 2767 methodology is widely used to gain insight in the technical status of systems and components. The basic principle is the description of components condition levels on a scale from 1 to 6, in which 1 represents the highest level. However, the NEN 2767 method does not say anything about the energy performance of elements. Another inspection method is the RgdBOEI, developed by Rijksgebouwendienst (Rijksgebouwendienst 2012). Besides the technical condition level of elements, this method also focuses on fire safety and more importantly, on the energy performance of components. The energy performance is indicated on a scale from 1 to 6 that suggests whether the component should be replaced or not. Although this inspection method supports finding the possible components subject to replacement from an energy efficiency perspective, there is one pitfall. The description of the different scale values indicates whether replacement of a component is financially profitable. This means that the auditor is expected to estimate costs and benefits. If any inaccuracy is present in the auditor's evaluation this can highly influence later decision-making.

Apart from a complete inspection of the building, another possibility to identify energy inefficient components is by reviewing the maintenance schedule. For every building component, activities are listed what helps gaining insight on these components. Based on this information, many building operators, maintenance or energy consultants can identify energy inefficient components. For example, characteristics such as age and type of heating system might indicate that replacement by a new technology can improve the energy efficiency. Note that the lack of or inaccurate information will negatively influence the identification process.

4.2.3. Identification of technical solutions

Identifying the specific technical solutions that can improve the energy efficiency is a tailor-made activity; every building is different and has unique characteristics. Besides that, many technologies are available. This makes identifying technical solutions a time-consuming activity and it is for good reason that solutions are sought to ease this identification step. Because improving energy efficiency is highly encouraged by national government and institutions, several documents are made available that list quick wins concerning energy efficiency. Note that these list are standardised and generalized and cannot provide custom made solutions. Besides these lists, tailor-made advise on possible energy efficiency improvements is often given by consultants and is called EPA (Energy Performance Advise). The EPA is a certified method based on ISSO 75 (ISSO Kennisinstituut voor de Installatiesector 2011), that provides a general approach to defining improvement opportunities. It provides the property owner with advice on what the current energy performance of a building is (by determining the Energy Label), what possible improvements are (technical systems and building elements), the cost, returns and payback time of these improvements and the projected decrease in carbon emission and improvement of the Energy Label. A sound EPA can only be provided if sufficient information on the property and its components is available.

Several decision-supporting tools are developed that provide building operators with technical improvement solutions based on standard lists of possible improvements. Examples of these tools are the ones developed by (Strachan & Banfill 2012) and (Augenbroe et al. 2009). Based on the data input concerning the current building state and criteria set by the tool user, the tools generate a list of improvement opportunities including financial estimations. Note that the information on the possible improvements is still somewhat standardised and only give an estimation concerning cost and projected results. This means that organisations should be careful with making decisions based on these estimations, although these decision support tools can be useful when to systematically identify opportunities in large property portfolios. A useful characteristic is that the tools try to select the 'best' technical solutions, considering that there are many solutions.

When energy inefficiencies are identified and localized, and technical solutions to eliminate these inefficiencies are found, the improvement opportunities are identified. However, this does not directly lead to all opportunities being or need to be exploited. Assessment will indicate what solutions to implement.

4.3. Opportunity assessment methods

Assessment of opportunities is necessary to determine the value of an opportunity. The value can be determined by weighing the benefits of the opportunity against the cost of exploiting the opportunity. On top of that, organisations should determine whether the value of an opportunity fits within their set objectives. The latter is not within the focus of this research. The assessment phase is the phase where actual decision-making on interventions is prepared. However, not only does incomplete information limit the possibility to determine the profitability of improvement opportunities, the use of incorrect information adds risk to the decisions that will be made based on the assessment. Therefore, it is important to apply sound assessment.

Many assessments comprise solely financial assessment. Organisations primarily invest in projects that are worth more than it costs (Brealey et al. 2011), and the most straight forward method to express value is in monetary terms. In most cases, only energy savings are included in the economic analysis, while other benefits of building renovation are neglected (Martinaitis et al. 2007). There are many financial valuation methods used in practice of which the one is sounder than the other. Although financial payback on energy efficiency interventions is crucial, payback is not always through direct financial return; it may be through improved reputation, more productive employees, increased market value of the property, etc. (Strachan & Banfill 2012). Unfortunately, results occurring from improvements other than results that are financially related are often not taken into account. Therefore, before going into detail on financial valuation approaches, other possible benefits, which organisations can take into account when assessing energy reduction measures, are mentioned.

4.3.1. Possible assessment criteria

By determining the reasons why organisations have implemented energy efficiency interventions, the potential other benefits of energy efficiency interventions can be identified. Remember that in the introduction was stated that the low potential financial gain is a reason retaining organisations from implementing interventions, but some organisations do decide to act and implement interventions. This indicates the presence of other types of incentives (Strachan & Banfill 2012) that mostly results from possible impacts. Property owners that do pay attention to lowering energy consumption appear committed to energy reduction mostly based on their environmental values (Junnila 2007), the long-term financial benefit is not always a primary incentive. It is therefore very important to provide organisations that are not (yet) committed to energy reduction with insight in possible other impacts.

Energy savings and carbon footprint

The savings in energy cost are often used in financial analysis, but the relative or absolute energy savings also are of importance. These savings will result in lower carbon emission, often expressed in carbon footprint. This footprint represents the emission of carbon dioxide equivalents (CO_2e) and is calculated by multiplying the energy use in kilowatt-hour electricity or cubic meter of gas with the emission per energy unit. Note that the carbon emission for electricity depends on how it is generated. In the light of Corporate Social Responsibility (CSR), many organisations report on their carbon footprint. It is to a growing extent accepted that enterprises must take steps to minimise the negative effects of their activities (MVO Platform 2012) and presenting carbon emission is the language of environmental performance in many large organisations (Strachan & Banfill 2012).

Improved sustainability ratings

Improving components energy efficiency will lead to improved sustainability ratings (if applicable) such as BREEAM or LEED. These ratings are often used to communicate externally what goals are achieved and can generate free publicity or marketing. However, there should be taken into consideration that often energy efficiency is only one topic assessed by the sustainability ratings. This means that a highly sustainability rating does not fully correlate with a highly energy efficient building (Hertzsch et al. 2012). Whereas the Energy Label is expected to reflect the energy efficiency, it actually is the standardised calculated efficiency that also takes for example the use of renewable sources into account.

Indoor Environmental Quality (IEQ) and employee productivity

The functional quality of a building influences the IEQ and consequently the productivity of buildings user (for specific building functions) and level of sick leave. The financial effects of this productivity can be calculated by using the quantitative relationship between the IEQ and productivity as done in the so called DUBO-versneller (Sustainable Building Launcher) developed by Royal HaskoningDHV and based on the REHVA guiding book (Wargocki & Seppanen 2006); a change in IEQ will result in an increased productivity what results in lower employee cost.

Asset value

Improving a building's performance will affect asset value by increasing either the internal (book) value or the market value. Especially the latter is hard to express because it is dependent on external forces. The internal asset value, or the accounting or book value, can be calculated by for example using the projected future cash flows as done in real estate investment analysis. This criterion is important for organisations that consider renting out or selling property; when improvements are not translated into increases rental income or bidding price, the benefits are negatively influenced.

Corporate image

Mentioned in literature relating to the above-mentioned impacts is the reputation or corporate image of an organisation. Taking responsibility towards the environment improves the green image of an organisation (Agentschap NL 2011b; Rooijers et al. 2010). Saving energy and communicating about this, or promoting the improved sustainability rating can affect the organisational performance by publicity. Secondly, a periodically updated index identified that the 100 most sustainable companies worldwide do not only limit their environmental impact, but also have a financial return that is 6% higher than of their competitors (Corporate Knight 2013) what implicates a positive relationship between a sustainable business model and company performance. Besides this, a building with high IEQ characteristics will result in satisfied employees (Rooijers et al. 2010) which increases the attractiveness of the organisations as an employer.

4.3.2. Financial valuation

The financial valuation of improvement opportunities is a crucial part of the assessment process. This mostly concerns measures for which substantial resources are required. In this paragraph, first multiple valuation methods are explained, hereafter, the type of costs that can be taken into account in a financial valuation are mentioned.

Valuation methods

There are multiple valuation methods used in practice and described in literature that have the aim to weigh the costs against the benefits of energy efficiency improvements. Currently, the most popular methods to quantify benefits of energy efficiency upgrading of buildings are the simple payback method, the return on investment (ROI), life cycle costing (LCC) and the net present value (NPV). Following an elaboration on these approaches with the aim to examine which methods are useful when assessing opportunities within building maintenance and repair.

An often-used and simple method to calculate the profitability of investing in energy efficiency improvements is by calculating the payback period; the investment costs are divided by the projected energy savings what results in the number of years it takes to earn the investment back.

$$Payback\ period = \frac{Initial\ investment}{Cash\ inflow\ per\ period}$$

When integrating energy efficiency improvement within BMR, a part of the investment costs for components can be covered with the projected maintenance expenditures for these components; these expenditures will be made independently from the energy efficiency improvements being implemented or not. This means that the only the additional required expenditures for the energy efficiency measure comprises the initial investment. Besides the payback calculation ignoring other expenses or savings during the lifetime of a measure, this calculation also ignores the time value of money (i.e. the value of an euro today is most likely not equal of the value of an euro in five years). On top of this, the payback calculation also disregards cost savings that occur after the payback period (Kulakowski 1999). This means that using a payback calculation to examine interventions cannot be named good practice. The simplicity of this method is counterbalanced by its drawbacks (Martinaitis et al. 2007).

The return on investment (ROI), or also named rate of return, can be calculated and indicates the efficiency of the investment. This is done by dividing the cost of the investment (i.e. the yield minus the initial investment) by the initial investment.

$$Return\ on\ investment = \frac{yield - initial\ investment}{initial\ investment}$$

The higher the ROI is, the higher the efficiency of the investment. For example a ROI of 0,5 (i.e. 50%) indicates that over the calculated time period, the investment yields a 50% return. Note that the ROI does not indicate the payback period, but singularly says something about the efficiency.

Energy efficiency interventions are often treated in isolation of other expenses and activities throughout its lifetime. For example, annual maintenance cost along the lifecycle might differ for the energy efficient replacement of a component compared to the traditional one-for-one replacement. Taking all the concerned cost into account of the entire lifetime of a component or building is named Lifecycle Cost Costing (LCC) or Life Cycle Analysis (LCA); this analysis results in cash flows occurring after the payback period also being taken into account. The discounted cash flow (DCF) is a method to calculate the value of the discounted cash flow accruing from a component's lifecycle on a different moment in time than its occurrence. Most often, DCF us used to determine the net present value (NPV) of cash flows over a period of time. The cash flows are discounted by using a discount rate. This discount rate is a percentage that at least covers the cost of capital, and possibly also represents a target rate of return (i.e. internal rate of return) (Watson & Head 2010). By the use of a discount rate, the option value (i.e. the money-value of waiting to invest) that holds organisations back from deciding to invest (Schleich 2009; Van Soest & Bulte 2001) is charted.

$$Net\ Present\ Value\ =\ C_0 + \frac{C_1}{1+d} + \frac{C_2}{(1+d)^2} + \cdots + \frac{C_t}{(1+d)^t}$$

$$Net\ Present\ Value\ (d, lc) = \sum_{t=0}^{lc} \frac{C_t}{(1+d)^t}$$

The above mathematical equations define the NPV for a time period (i.e. in this case the lifecycle) *lc* with discount rate *d* in which *t* represents time and C_t the total cash flow at *t*. The sigma sign shows that the sum of discounted cash flows for each time step over period *N* is together giving the NPV. An investment with NPV > 0 is considered as feasible, because it determines that the sum of all discounted cash flows over a period of time is not negative. The NPV is the difference between a project's value and its cost (Brealey et al. 2011).

Note that in all the above valuation methods, energy savings are considered as 'income', while no money is physically returning to an organisation at all; less money is required to pay the energy bill. Both NPV and payback time do not say anything about the investment required, while this investment can be a huge barrier to organisations. Compared to the payback calculation, the NPV as a support to LCA gives a much more complete overview and realistic approach to providing insight in the financial impact. However, performing this calculation requires more knowledge and expertise. The required effort to do this might refrain organisations from performing such analyses.

Life cycle costs

Life Cycle Costing is about getting the full picture of how much equipment will cost, over its whole life (Carbon Trust 2010). To perform a lifecycle analysis, all the cost that will occur during a components lifecycle should be known. This is especially of importance because the possible presence of hidden costs such as production costs or overhead costs of energy management refrain organisations from investing (Bonde 2012; Schleich 2009). The following elements can be taken into account: investment cost, maintenance cost, depreciation cost, energy cost. While investment, maintenance and energy cost are straightforward and are used more often in calculations, depreciation cost needs clarification. Depreciation of elements concerns the decrease in value over time, mostly reflected on the balance sheet of an organisation. The end of the economic lifetime (i.e. when the value on the balance sheet of that element equals zero) indicates the end of the service time or lifetime of the element. This means that if a component is replaced earlier than the end of economic lifetime, there is still value left on the balance sheet that needs to be depreciated. This value will be considered as cost at the moment that the component is replaced and needs to be incorporated in the valuation of the investment. Besides costs, 'income' or decrease in cost should as well be taken into account. Of course, energy savings are a very important element. The cost of energy (i.e. per unit) can highly differ between organisations. Not only does this relate to the type of energy contract the organisation has, but also whether energy is generated within the organisation or not. Another type of income can come from subsidies. At this moment, the EIA (Dutch: Energie Investeringsaftrek) and MIA (Dutch: Milieu Investeringsaftrek) are available and represent a fiscal advantage when organisations implement energy efficiency improving measures. Apart from including all the costs and income occurring in a component lifecycle, also economic factors should be taken into account. These factors mainly comprise price increase in maintenance and energy costs. All given valuation methods are dependent on future energy prices (Martinaitis et al. 2007), especially in an economic situation where the energy prices are uncertain. In practice, these economic factors are mostly not included because it is hard to predict specific percentages.

Calculating the lifecycle cost of an improvement intervention can be time consuming if many aspects need to be included, especially when multiple interventions need to be assessed. However, remember that many interventions comprise activities incremental to maintenance activities and cost that are already occurring. This means that the additional costs and income can be used in an LCA instead of all cost to determine whether the NPV of the interventions is positive. A positive NPV indicates that the value of the interventions is higher than the value of the current component. This means that implementation of the measure would economically be sound.

4.3.3. Scenario analysis

Multiple resources name the importance of assessing different opportunities by the means of scenario analysis. The purpose of scenario analysis is to explore and assess several possible futures in a systematic way (Schwartz 1996). Schwartz notes that scenarios are tools for ordering perceptions about alternative future environments that results in better decisions about the future because it helps thinking through opportunities and consequences of future scenarios; scenario analysis enables thinking about policies that might not be considered otherwise. The importance of scenario analysis within this research is applicable on two levels. Firstly, because there might not be an unambiguous best (technical) solution at first hand and further analysis is required to find out what the best solution is. Secondly, because there might be different combinations of solutions or different strategies, that will lead to different impacts. Scenario analysis is necessary to gain insight in the impact of these strategies. An overview of the results, pros and cons of the scenarios can help organisations to decide what scenario or strategy to follow.

Comparing multiple possibilities by scenario analysis can be time-consuming. Therefore, several decision support tools are developed with the aim to optimise the ambition level of the organisation with technical improvement opportunities using logarithms (e.g. Juan et al. 2010) or have developed more sophisticated appraisal methods (e.g. Martinaitis et al. 2007). The optimisation tools support the model user (i.e. property owners or building operators) by determining the improvement measures based on property characteristics and organisational aims and limitations concerning for example energy savings or budget availability. These appraisal or assessment methods aim to combine energy efficiency benefits with building improvement benefits and choose the optimum scenario fitting the organisations aims. However, within BMR no methods are available that support choosing the most valuable scenario.

4.4. Summary

This chapter focused on identification and assessment approaches of improvement opportunities regarding addressing energy efficiency within property maintenance.

The process of opportunity identification comprises the identification of inefficiency, components subject to improvement and technical solutions. The lack of information on the energy consumption of a property and thus the lack of information on the energy performance prevent owners from identifying a saving potential. Identifying improvement opportunities goes accompanied by specific technical knowledge of the building systems and elements. Although building operators have probably the most knowledge on the building characteristics, there can be questioned whether they are aware of the newest technologies and solutions concerning energy efficiency. Problems such as a broken window are easy to solve, whereas determining what the best solution is for a new heating system is more difficult to identify for someone that lacks specific knowledge. Note that a large part of organisations rely on external contractors when it comes to maintenance of property, what means that specific technological knowledge is often not available in-house and thus organisations rely on the technical knowledge of their contractors or consultants concerning improvement of their property performance. The identification of the right opportunities of interest for assessment is crucial to maximise efficiency improvement, what means that in the identification phase having access to sufficient information about the property of subject is essential.

Assessment of opportunities should provide insight in the impact of the interventions concerning both finance and benefits such as reduced carbon footprint, increased environmental quality, sustainability ratings, corporate image, and possibly asset value. However, not all the aforementioned elements are easy to express and therefore often not taken into account. Financial assessment of interventions ideally is performed by Lifecycle Analysis (LCA), in which all occurring costs over a components lifetime are included. With the help of the discounted cash flow method, the net present value (NPV) of improvement possibilities can be calculated. However, the use of LCA and NPV is not completely common in the field of BMR. Besides this, assessing the long-term effects of a combination of interventions while taking economic factors such as price increases into account further complicates the assessment process. Therefore, support is needed of a tool that provides help in performing the assessment of a combination of interventions over a period of time.

5. Dynamic assessment tool

This chapter focuses on the development of an assessment tool that enables to evaluate or assess energy efficiency improving measures as a part of total maintenance activities. The previous two chapters elaborated on the context of improving the energy efficiency of property, building maintenance and repair (BMR), the environment in which decisions on improvements are made, and the possible improvement identification and assessment procedure. The latter part indicated the need for an easy to use model that provides insight in the long-term effects of energy efficient BMR. This chapter elaborates on the objective, methodology and design of the developed tool. The tool is validated and verified by a case study elaborated in chapter 6.

5.1. Objective of the tool

The main objective of the tool is to support managerial decision-making relating to building maintenance and repair, by helping in providing insight in the effects on maintenance expenditures and energy expenditures over a period of time for one or more maintenance strategies. The need for this type of assessment tool results from assessment being a complex and time-consuming activity. Four issues have been identified as described in the previous chapters that are aimed being solved with the development of the assessment tool:

- There is often not a straightforward solution or one combination of interventions that will lead to improved energy efficiency, but rather multiple possibilities. Scenario analysis can support assessing multiple strategies but is time-consuming to perform.
- Energy efficiency interventions or energy efficient maintenance strategies can be assessed on multiple performance criteria that require sophisticated assessment methods accompanied by more complex calculations or analysis.
- Because maintenance cost and energy savings resulting from energy efficiency measures are often not reviewed together and/or in the perspective of all maintenance activities and total energy use, decision making takes place on incomplete information.
- Financial effects are often assessed incorrectly because incomplete information is used, environmental or economic factors are not included and incorrect or incomplete valuation methods are used.

The above lead to the objective to develop a tool that gives organisations or building operators the possibility to structurally examine improvement opportunities by providing assessment data. Given this information, the tool user should be able to make a decision on what maintenance strategy to follow.

5.2. Methodology: System Dynamics

5.2.1. Introduction to System Dynamics

The decision support tool consists of a model that is based on the principles of System Dynamics (SD). The aim of SD is to improve the understanding of the ways in which organisational performance is related to for example its internal structure and operating policies (Sterman 2000). A basic principle of System Dynamics is its ability to simulate a system over time using stocks and flows. Flows represent a change in stock by accumulating incoming and outgoing flows of a stock over a period of time. These flows and stocks are influenced by variables that can be of quantitative as well as qualitative nature. This principle can easily be illustrated by the so-called bathtub example. Consider the amount of water in the bathtub as the stock, which is influenced by an inflow and outflow. The water tap determines the inflow, and the drain in this case determines the outflow. The inflow and outflows can be influenced by various variables. For example, the inflow of the bathtub is dependent on to what extent the tap is turned and the outflow is influenced by whether the bathtub stopper is placed or removed. Specific formulas determine the underlying relationship between these variables. A SD model can exist of multiple stocks, flows and variables that are interrelated. By simulating the model over a set amount of time, the variables, inflows, outflows, and stock levels will change and vary in values at different moments in time. The combination of values is saved as a dataset and this data can easily be visualised in graphs to provide the model user with information.

5.2.2. Justification and application of the methodology

In this research, SD is used primarily for its ability to simulate behaviour of multiple interdependent and dependent components and its ability to handle much quantitative information, resulting in outcomes that are easy to read and interpret and so consequently can support decision making. The software package used to develop the model is Vensim PLE Plus. By the use of this software, a model can be created that separates specific input (from a case) from the analysis method and output, what aids structuring and managing data and information. Already twenty years ago John D. Sterman mentioned the theoretical relevance of SD as a supportive tool in management of the built environment. Not only can SD cope with extremely complex and highly dynamic systems that consist of multiple interdependent components, it is also able to handle multiple feedback processes, nonlinear relationships and quantitative as well as qualitative data that one is concerned within large projects (Sterman 1992). Following the three main functionalities of the tool in which SD fulfils a supportive and essential role.

Main assessment variables of the model

The aim of the tool is to assess maintenance activities regarding its financial effects and energy performance effects. Therefore, assessment criteria need to be determined so these can be included in the calculation model. Possible assessment criteria consist of financial aspects and more qualitative elements as elaborated in paragraph 4.3.1. Because the focus of this research is to contribute to seizing opportunities within building maintenance activities, not all the assessment criteria were taken into account and a selection was made to determine variables that are used as model parameters. Three main criteria are considered the most important to aid decision-making: 1) total energy and maintenance expenditures, 2) energy savings and 3) carbon footprint. Besides these three assessment variables, many other parameters are used in the model as further explained in paragraph 5.3.2. These parameters are used to either aid in calculating the three main parameter values, or turn the parameter values into useful variables that can support decision-making. This indicates that the parameters or variables used in the model relate to one another. SD aids in structurally describing these interrelations by the use of formulas.

The use of scenario thinking

To compare the standard or base strategy to BMR with a new strategy in which energy efficient measures are integrated, scenario thinking is applied. System Dynamics enables scenario analysis by 1) having the ability to simulate a model under different circumstances by varying parameter values and by 2) developing multiple sub-systems of which data can be compared. The first utility is applied by using economic factors that can be varied: inflation rate, and the change in maintenance, electricity and gas price. These four factors influence the energy and maintenance cost. The second utility is applied by developing two sub-models: the first handles the calculations for the base strategy or base scenario. The second sub-model handles the calculations for the new strategy or new scenario. Both sub-systems need to import external data relating to the case that is been assessed.

Financial valuation method

A sound financial valuation method is required to enable comparing scenarios concerning the two main financial assessment variables. The valuation method that is used in the model is the discounted cash flow method, translated into Net Present Value (NPV). The NPV discounts cash flows back to the present value what enables comparing cash flows that occur on different moments in time. More explanation on this and other valuation methods is given in paragraph 4.3.2. The System Dynamics software Vensim offers predefined formulas to aid in using NPV calculations. The NPV of the energy and maintenance expenditures, the NPV of the additional maintenance expenditures regarding the base scenario and the NPV of the energy expenditure savings are calculated. The sum of the two latter represents the NPV of the energy efficiency interventions.

5.3. Tool design

5.3.1. Overview

The core structure of the assessment tool consists of two parts: the user interface and the calculation model. Figure 5.1 visualises this core structure in which can be seen that the user interface aids in connecting the calculation model input and consequently representing the model output. Following an extensive description of the calculation model and the User Interface.

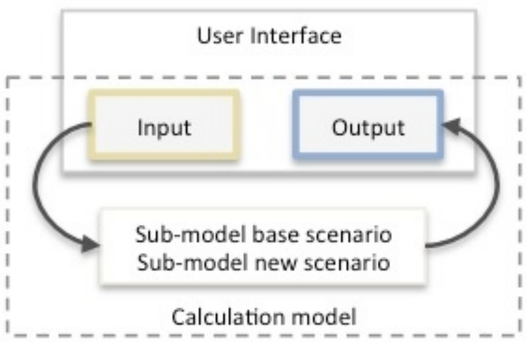


Figure 5.1 – Core structure of the assessment tool

5.3.2. The calculation model

The total calculation model consists of two sub-models (i.e. for the base and new scenario), which both contain three types of variables: input variables, output variables, and variables required to turn the input variables into the output variables. Figure 5.2 shows the input variables and output variables. The input consists of case specific and non-case specific input. The maintenance expenditures are split into the non-energy efficiency related and energy efficiency related maintenance expenditures. This means that regarding the input, ‘standard’ maintenance cost are isolated from the maintenance cost that concern the component(s) subject to energy efficiency improvement. This split is required to enable financial assessment of cost and benefit of the energy efficiency improving measures. It means that for both base and new scenario, the non-energy efficiency related maintenance expenditures are equal, but the energy efficiency related maintenance expenditures differ and need to be imported for both the scenarios. This is also necessary for the expected change in energy use (gas and electricity). Other case specific input concerns the initial energy use (gas and electricity) and energy price (gas and electricity). Finally, the four economic rates and one financial valuation rate have to be determined.

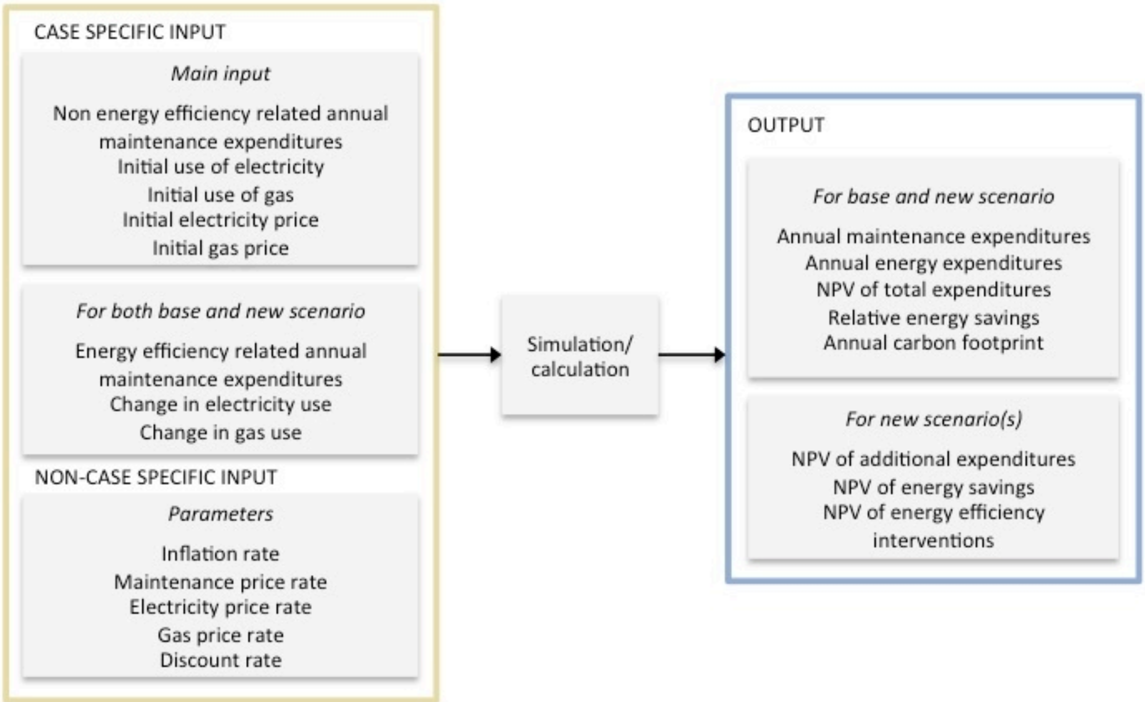


Figure 5.2 – In- and output of the calculation model

The tool generates output values for both base and new scenario concerning the following variables: maintenance and energy expenditures, energy savings and carbon footprint. As stated before, the calculation model exists of two sub-models; for both the base scenario and new scenario a sub-model is developed so the scenarios can be simulated simultaneously. The main part of the sub-models correspond, however, the new scenario sub-model is extended by variables that aid in calculating the NPV of the additional maintenance expenditure, the NPV of the energy expenditure savings and consequently the NPV of the energy efficiency interventions. Following both sub-models and explanation of the variables. An extensive and step-by-step explanation is provided in Appendix 6.

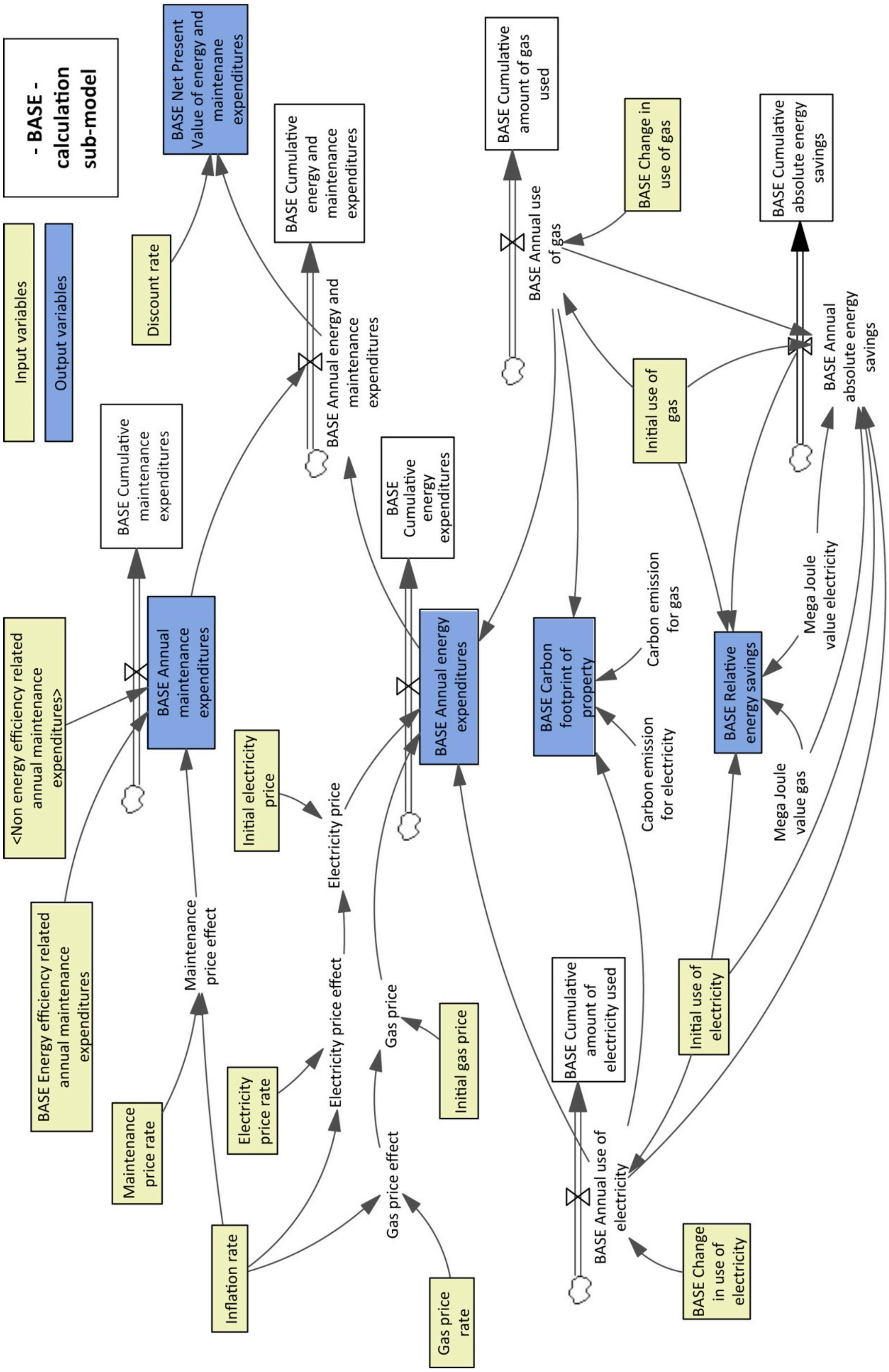


Figure 5.3 – Calculation sub-model base scenario

The following table mentions all the variables of the calculation sub-models as shown in Figure 5.3 and Figure 5.4. Note that within the table, the prefixes 'BASE' or 'NEW' are not mentioned.

Table 5.1 – Calculation model variables explanation part I

Variables part I – main part of base and new calculation sub-model		
Name	**Units**	**Description**
Annual absolute energy savings	Mega Joule/year	Sum of annual gas and electricity savings calculated to Mega Joule
Annual energy and maintenance expenditures	Euro/year	Represents the sum of annual energy expenditures and annual maintenance expenditures
Annual energy expenditures	Euro/year	Indicates the annual energy expenditures resulting from use of gas and electricity
Annual maintenance expenditures	Euro/year	Represents the annual maintenance expenditures, based on the non energy efficiency and energy efficiency related maintenance expenditures
Annual use of electricity	Kilowatt hour/year	Annual use of electricity in kilowatt hour
Annual use of gas	Cubic meter of gas/year	Annual use of gas in cubic meter
Carbon emission for electricity	Kilogram CO_2/kilowatt hour	Carbon dioxide emission in kilogram per kilowatt hour electricity (0.59686)
Carbon emission for gas	Kilogram CO_2/cubic meter of gas	Carbon dioxide emission in kilogram per cubic meter of gas (1.79772)
Carbon footprint of property	Kilogram CO_2/year	Sum of carbon emission in kilogram resulting from annual use of electricity and gas
Change in use of electricity (for the purpose of sensitivity testing)	Kilowatt hour/year	Change in annual use of electricity. A positive value indicates a decrease in energy use and a negative value indicates an increase.
Change in use of gas (for the purpose of sensitivity testing)	Cubic meter of gas/year	Change in annual use of gas. A positive value indicates a decrease in energy use and a negative value indicates an increase
Cumulative absolute energy savings	Mega Joule	Accumulation of annual use of energy in Mega Joule
Cumulative amount of electricity used	Kilowatt hour	Accumulation of annual use of electricity
Cumulative amount of gas used	Cubic meter of gas	Accumulation of annual use of gas
Cumulative energy and maintenance expenditures	Euro	Accumulation of annual energy and maintenance expenditures
Cumulative energy expenditures	Euro	Accumulation of annual energy expenditures
Cumulative maintenance expenditures	Euro	Accumulation of annual maintenance expenditures

Discount rate	Fraction	The rate with which values are discounted in the calculation of the net present values
Electricity price	Euro/kilowatt hour	Represents the electricity price at t
Electricity price effect	Dmnl	The multiplication factor which will turn the initial electricity price in the actual electricity price
Electricity price rate	Fraction	Indicates the change in electricity price (corrected for inflation)
Energy-efficiency related annual maintenance expenditures	Euro/year	Annual maintenance expenditures concerning the energy efficiency interventions
Gas price	Euro/cubic meter of gas	Represents the gas price at t
Gas price effect	Dmnl	The multiplication factor which will turn the initial gas price in the actual gas price
Gas price rate	Fraction	Indicates the change in gas price
Inflation rate	Fraction	Indicates the change in the general level of prices and goods (consumer price index)
Initial electricity price	Euro/kilowatt hour	The initial price of a kilowatt hour electricity at t_0
Initial gas price	Euro/cubic meter of gas	The price of a cubic meter of gas at t_0
Initial use of electricity	Kilowatt hour/year	The annual use of electricity at t_0
Initial use of gas	Cubic meter of gas/year	The annual use of gas at t_0
Maintenance price effect	Dmnl	The multiplication factor which will turn the maintenance expenditures in the actual annual maintenance expenditures
Maintenance price rate	Fraction	Indicates the change in price (increase or decrease) of products and services concerning buildings (corrected for inflation)
Mega Joule value electricity	MJ/kilowatt hour	Amount of Mega Joule in one unit of electricity (3.6)
Mega Joule value gas	MJ/cubic meter of gas	Amount of Mega Joule in one unit of gas (35.2)
Net Present Value of energy and maintenance expenditures	Euro	Represents the sum of Present Values of the annual energy expenditures and annual maintenance expenditures
Non-energy efficiency related annual maintenance expenditures	Euro/year	Isolated annual maintenance expenditures not concerning the energy efficiency interventions
Relative energy savings	Percentage	Percentage difference in energy use between base and new scenario, based on the energy use in Mega Joule

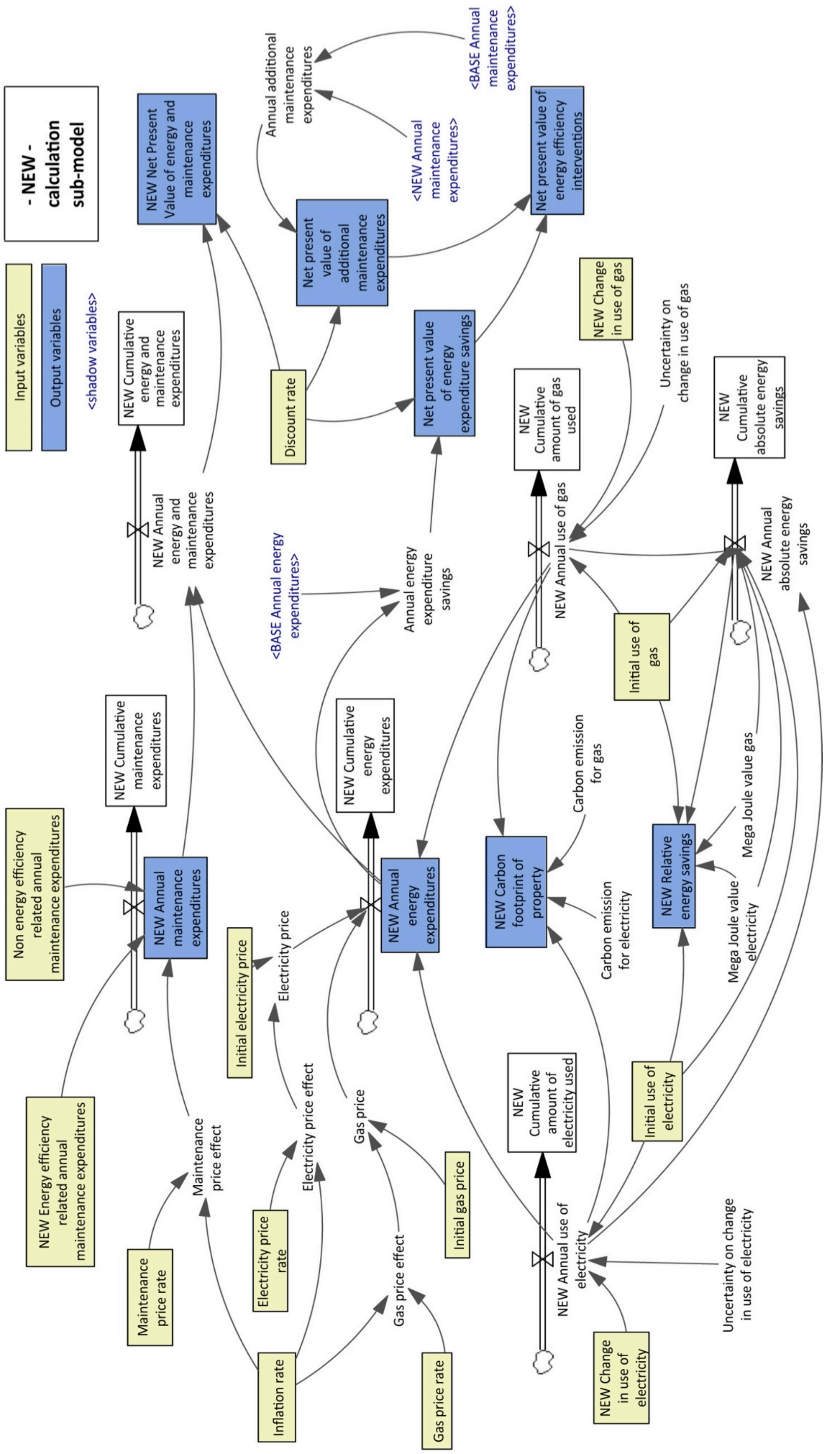


Figure 5.4 – Calculation sub-model new scenario

Table 5.2 – Calculation model variables explanation part II

Variables part II – additional variables new scenario calculation sheet		
Name	**Units**	**Description**
Annual additional maintenance expenditures	Euro/year	Represents the difference between annual maintenance expenditures of the base and new scenario. A negative value indicates additional expenditures, a positive value indicates less expenditures in the new scenario compared to base scenario.
Annual energy expenditure savings	Euro/year	Represents the difference between annual energy expenditures of the base and new scenario. A positive value indicates savings
Net Present Value of additional maintenance expenditures	Euro	Represents the sum of Present Values of the annual additional maintenance expenditures
Net Present Value of energy expenditure savings	Euro	Represents the sum of Present Values of the annual energy expenditure savings
Net Present Value of energy efficiency interventions	Euro	Represents the sum of Present Values of the annual energy expenditures and the annual additional maintenance expenditures. A positive value indicates that the value of the interventions is higher than its cost

The above table shows the five variables additional to the variables shown Table 5.1 that are part of the new scenario sub-model. The main part of the sub-models leads to the Net Present Value of the total energy and maintenance expenditures, whereas the five additional variables focus on assessment on singularly the energy efficiency improvement part.

5.3.3. User interface

To guide the model user, a two-parted user interface (UI) was developed. The UI explains the user what steps to take and what simulation outcome is visualised. In this way, the user does not need to handle the calculation model itself; this part is mostly hard to understand due to its complexity and understanding this complexity is not relevant to interpret the outcomes of the simulation. Following the input window (Figure 5.5) and output window (Figure 5.6) that together represent the user interface of the assessment tool. In the input window, the tool user is guided through six steps that focus on linking and entering the data input to the model. The output window provides the outcome of the model simulation and gives the possibility to change the economic parameters while directly seeing the effects in the model outcomes. An essential aspect of the output window is that it combines the results of both scenarios (i.e. both calculation sub-models) in graphs and tables. This makes it easier for the user to read and interpret the outcome. All eight output variables mentioned in Figure 5.2 are visible on the output window. Note that the data shown in Figure 5.6 concerns the case study performed in this research, further explained in paragraph 6.4.

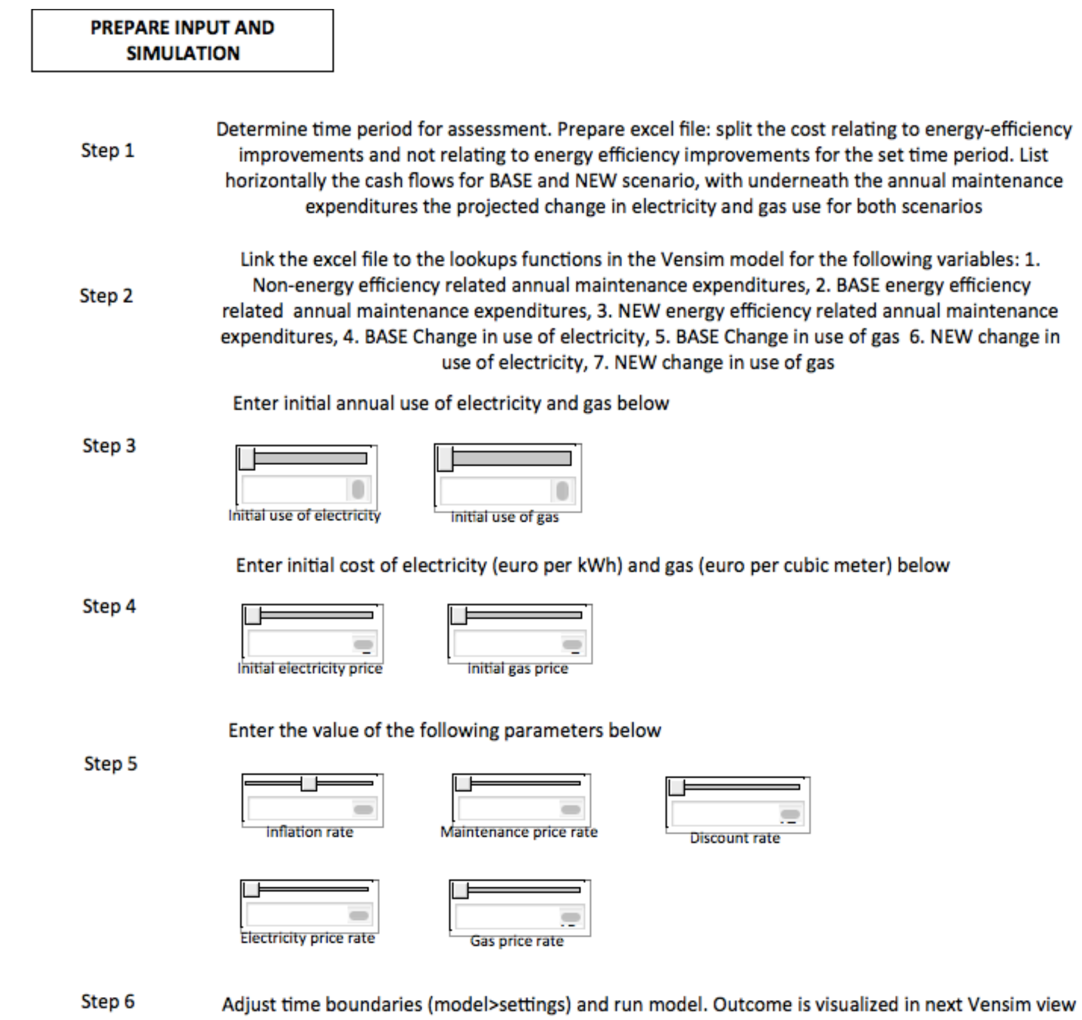


Figure 5.5 – User Interface: input window

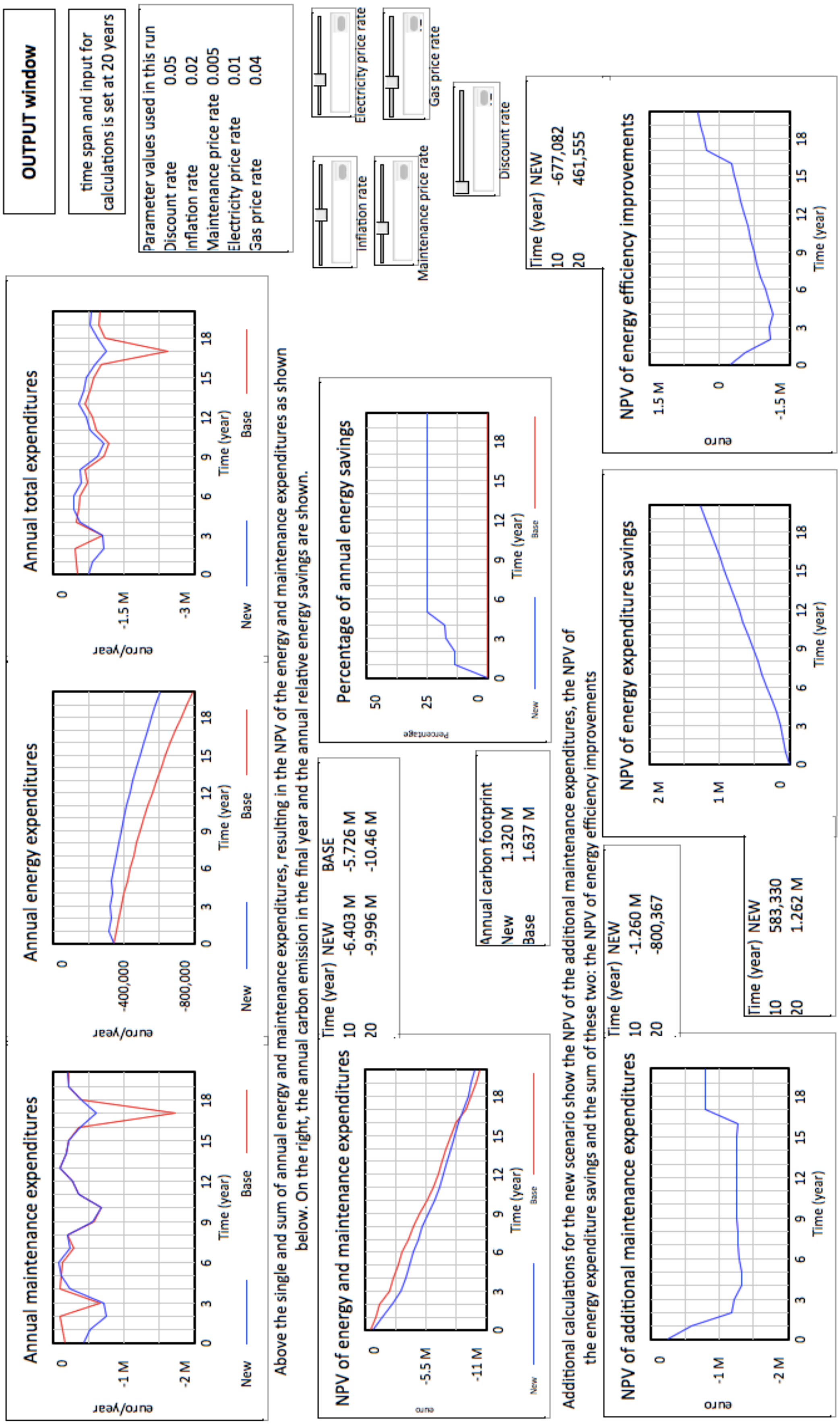


Figure 5.6 – User Interface: output window

5.4. Sensitivity analysis

5.4.1. Sensitivity testing

All models are largely based on assumptions to enable simulating a system and future behaviour. This means that the outcome of a simulation will likely differ from what will happen in reality. Therefore, the robustness of the conclusions to uncertainty in the assumptions must be tested. In other words, the sensitivity of the outcome under changing parameters needs to be analysed. Sensitivity analysis asks whether conclusions change in ways important to the initial purpose when assumptions are varied over the plausible range of uncertainty (Sterman 2000). To perform a sensitivity analysis, identification of the uncertain parameters and an analysis method need to be determined.

5.4.2. Uncertain parameters

The following parameters in the calculation model, for which assumptions are made, are considered subject to uncertainty and a change in value will affect the outcome of the model:

- Inflation rate, maintenance price rate, electricity price rate and gas price rate: these four variables depend on many factors mainly relating to for example economic development. The values used in the base run were determined using an average value based on statistical data from the past. However, the true value can differ from this average.
- Change in use of electricity and gas: the change in use of electricity and gas is calculated, ideally with as much precision as possible. However, the saving calculation might be based on inaccurate data and besides that, the use of electricity and gas is also influenced by other variables such as user behaviour.

5.4.3. Analysis method: Monte Carlo Analysis

Several approaches are available that support sensitivity testing. For this research, Monte Carlo Analysis (MCA) was used. A Monte Carlo test builds models by substituting a range of values for the parameters that are uncertain and simulating the calculation model using these different range of values. The combination of outcomes of these simulation runs shows the distribution of possible outcome values. A very important part is the probability distribution of the parameter value that indicates not only the possible parameter value (or uncertainty range) but also the probability of this value to occur. MCA is, because the above description, also called a variance-based testing method.

MCA is used because of the following reasons: 1) the model can be tested by varying the six uncertain parameters randomly (i.e. multivariate testing) because all factors are independent. This is possible because the economic indicators are all acyclic, what means that they do not show specific behaviour in a specific economic situation (e.g. energy prices will not always drop or always rise in an economic crisis). Besides this, they do not correlate with each other; for example in a situation where the inflation rate is high, maintenance prices can either increase or decrease. The uncertainty present in the projected change in use of electricity and gas are also independent from each other; a deviation in gas use does not have to imply a deviation in electricity use and vice versa. 2) There is not one specific scenario that is expected and should be tested, but rather a range of possible scenarios resulting from varying parameter values. MCA can support in randomly selecting combinations of parameter values for a large number of iterations.

The selected probability distributions in this research are the triangular and the uniform distribution (see Figure 5.7). Both are bounded distributions, what means that the parameters values are restricted by a minimum and maximum value. An example of an unbounded distribution is the normal distribution that theoretically extends from minus infinity to plus infinity. The normal distribution is also an example of a parametric distribution, whereas the triangular and uniform distributions are example of non-parametric distributions. Non-parametric distributions are also called empirical distributions and are useful in practical mathematical problems because they are easy to understand. Parametric distributions should be selected if either the theory underpinning the distribution applies to the particular situation, what requires a greater knowledge of the underlying assumptions (van Hauwermeiren et al. 2012); this is considered not applicable in this research. The triangular distribution is described by a minimum (a), maximum (c), and mode or peak value (c). The peak value determines the most likely value. In the uniform distribution, every value has the same probability and is in between a minimum (a) and maximum (b). Note that for both the graph areas the accumulation is 1, which represents the sum of the probability of all the possible parameter values.

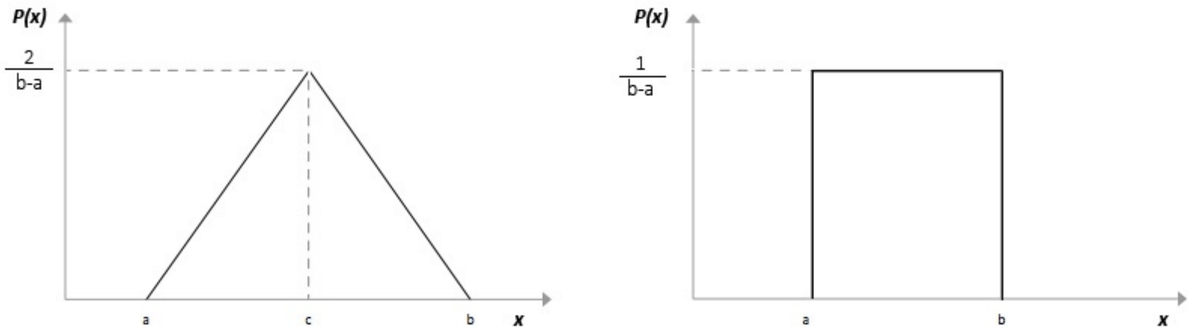


Figure 5.7 – Triangular and uniform probabilistic distributions

The triangular distribution is used for the inflation, the maintenance price, the electricity price and the gas price rate. This means that the mean value is expected to have a higher probability. This is due to, in this research, the mean value being based on the average values in the past years. The uniform distribution is used for the uncertainty on change in use of electricity and gas. The use of energy is influenced by various factors and the probability that the actual use will be for example 5% higher or lower is considered equal. A sensitivity analysis is applied in this research case study, which is further elaborated in paragraph 6.3.2. The specific range of uncertainty of the parameter values is also discussed in this paragraph.

6. Case study

This part focuses on applying the knowledge obtained from literature research and expert interviews and testing the assessment tool on a case study object. The specific case study object is the City Hall of Nijmegen, which is part of the municipal real estate portfolio of Nijmegen. The City Hall can be seen as the flagship of the municipality due to its public function and central location.

6.1. Case description

6.1.1. The municipal environment

In the Netherlands, municipalities are the smallest local governmental body and own large property portfolios; in total, the Dutch municipalities together own 43 million m^2, what is of comparable size of the Dutch office real estate sector (Ten Have et al. 2012). The building portfolios consist of municipal offices, sport facilities, cultural real estate, educational institutions and health facilities. Recent research determined that within public real estate, an annual potential energy saving of 450 million euro is possible (Agentschap NL 2013a). Municipalities are, fulfilling a public function, expected to play an exemplary role when it comes to sustainability and energy saving. It is therefore not surprising that 90% of 25 largest municipalities in the Netherlands states having determined specific energy reduction goals and sustainability objectives of which 80% specifically concerning their real estate portfolio. Even 75% of the same municipalities consider themselves being a front-runner when it comes to pursuing sustainability goals. However, over a third of the municipalities are not even certain of achieving their own objectives (Ten Have et al. 2012). It seems that although many municipalities are willing, the actual transition has not yet started. Even while municipalities are responsible for law enforcement concerning energy efficiency measures, they are not all fully compliant themselves.

6.1.2. Municipality of Nijmegen

The property portfolio of the municipality of Nijmegen, the Netherlands, consists of over 500 properties. The consulting company Royal HaskoningDHV is managing agent concerning the maintenance of the property portfolio. In 2010, an extensive sustainability project was started with the aim to improve the energy efficiency of the portfolio. The motive for this current sustainability project was an investigation that concluded 64% of the electricity use within the municipal organisation resulted from the municipal buildings and 100% of the gas use (Agentschap NL 2013c). At this moment, several projects are started that aim at improving the energy efficiency of specific property. When it comes to pursuing sustainability objectives and translating strategic objectives into operational actions, Nijmegen can be considered within Dutch municipalities as one of the front runners.

With the aim to limit the case study to a manageable size, one building out of the property portfolio was selected to further focus the case study on: the City Hall. This building is situated at de Korte Nieuwstraat 6 in the city centre of Nijmegen. It covers an area of 14,920 m^2 and four floors, excluding the parking garage underneath the building, and was built in 1982. The historic part of the city hall (built in 1555), adjacent to the new part, is left out of context for this research due to its monumental status that limits energy efficiency improvements. Because of its public function the City Hall is one of the first properties of focus within the sustainability project executed by the municipality at this moment.

6.2. Identification of energy efficiency interventions

The municipality of Nijmegen does not actively monitor the energy use of their property portfolio; for the City Hall invoice checking was the most detailed level possible, showing a monthly electricity and gas use for the building. The average use of energy compared to the average use of energy for offices given by Agentschap NL (Table 6.1) shows that the average use of the City Hall is above the national average. Besides this, the current Energy Index of the building is 1.68 (Label F). Both data indicate the possibility for an improvement potential.

Table 6.1 – Current energy use City Hall

	Yearly average (2006-2011)	Per m^2	Average use per m^2 (SenterNovem 2013a)
Use of electricity	1,985,797 kWh	133 kWh	109 kWh
Use of gas	251,570 m^3	28 m^3	20 m^3

The lack of energy monitoring disables the possibility to assess system specific behaviour. Although no specific opportunities can be identified, in general there can be assumed that in large building the service systems do not work optimally without active monitoring. According to professionals, for this case there can be assumed that 10% of the energy use (i.e. 10% electricity and 10% gas) can be saved if active monitoring is performed. The following steps were followed to determine other improvement opportunities:

- The former EPA-U (Energy Performance Advice for non-residential buildings) documents were considered.
- Within the current maintenance plan, energy efficiency influencing activities were identified.
- Expert interviews were performed to gain knowledge on technologies and costs.

Consequently, a list of possible interventions has been compiled of which Table 6.2 shows the result. Note that for this case, multiple technological possibilities were not assessed due to time constraints. This means that also other interventions are possible and the selected list is one example of a combination of interventions. For all the interventions the NPV of the lifetime was calculated in comparison with the current component. Explanation on the performed energy saving calculations can be found in Appendix 7. The scheduled year for the intervention is based on two criteria:

1) In case of an additional intervention, there is questioned whether the intervention can be combined with scheduled maintenance. For example, the placement of roof insulation is scheduled in year 4, together with the replacement of the roof plating.
2) If multiple large maintenance activities are scheduled in one year, there is examined what activities can be rescheduled to spread maintenance cost and minimise user inconvenience. For example, the replacement of glazing in the wooden window frames and replacement of the aluminum window frames was spread over year 0 and 1 because two reasons. Firstly, the glazing replacement could be easily combined with preventative maintenance in year 0 (i.e. painting of window frames). Secondly, replacing the window frames in year 0 as well will lead to a peak in maintenance expenditures and by scheduling this activity in year two, the maintenance expenditures are spread over the two years and the building can stay in use during the replacement activities.

Table 6.2 – Possible energy savings for the identified energy efficiency interventions

	Intervention	Type	Savings in kWh	Savings in m^3	Implement in year
1	Floor insulation	Placement		12,747	0
2	Roof insulation	Placement		31,909	4
3	Triple HR glazing	Replacement		17,433	0
4	Aluminum window frames	Replacement		16,364	1
5	Air Handling Unit with Speed controlled fans and Heat and steam recovery	Replacement	128,476		3
6	Speed controlled fans in small Air Handling Units	Replacement	7,410		4
7	Speed controlled pumps	Replacement	9,880		1-10
8	Emergency LED lighting	Replacement	5,606		0
9	Continuous commissioning service systems		10%	10%	every
	Total possible annual savings		**151,372**	**78,453**	

Gas, electricity and geothermal heat pumps were also proposed interventions in the EPA-U. However, these measures relate to energy generation instead of improving energy efficiency and require large investments and were therefore not taken into consideration. Besides this, the possibility for green roofs was investigated. However, the adoption cost for a green roof and the maintenance cost are considerably high. Compared to 'normal' roof insulation, the life cycle costs are much higher and therefore this option is not further taken into consideration. If all the above interventions are implemented, the energy label of the City Hall will increase to Label C (EI=1.22)

The following problems were identified when identifying improvement opportunities:

1) The quality of information on current state of the building is low; information is incomplete and not up to date. The incompleteness is caused partially by different departments being concerned with the property (Environmental Department and BMR) and a lack of information exchange, plus the maintenance activities being outsourced in the past without solid information management.
2) The maintenance plan is not completely trustworthy due to some maintenance activities being postponed without proper notification. In other words, some activities were initially scheduled a few years ago but are still not executed.
3) Standardised lists such as resulting from an EPA-U advice are incomplete or were based on wrong assumptions. For example, the quality of the glazing was much better than noticed during the last EPA-U assessment.

In this case study, relatively much information is available and nevertheless several crucial problems were experienced that hampered the process and influence the reliability of the information that is gathered. This questions whether for other cases, where probably even less information is available, possibly more or bigger problems are faced when identifying improvement opportunities.

6.3. Assessment of two maintenance strategies

The assessment tool is used to compare the old maintenance schedule to the adapted schedule based on the nine interventions shown in the previous paragraph. The new cash flows and the projected energy savings are used to run the SD-model to 1) test the developed SD model and 2) to assess the effects on the organisation for this specific case.

6.3.1. Data input base run

The cash flows used as input to the assessment tool are a result of the planned maintenance activities and can be found in Appendix 8. As mentioned before, the model gives the possibility to split the energy efficiency related expenditures from the non-energy efficiency related expenditures what means that three cash flows are linked to the calculation model. The base scenario scheduled maintenance includes the activities of the traditional maintenance plan. For the new scenario expenditures, the activities include the chosen energy efficiency interventions. The differences in activities concerning the energy efficiency related interventions are shown in Table 6.3. The additional and change in maintenance expenditures are included in the cash flows by adding the additional expenditures and by adapting other maintenance costs where necessary. Besides this, the expected change in energy use in listed in the first year after the intervention is implemented.

Table 6.3 – Difference between base and new maintenance scenario

	Base scenario	**New scenario**
1	-	Floor insulation (year 0)
2	Replacement of roof plating (year 4)	Replacement of roof plating including roof insulation (year 4)
3	Replacement by same type of glazing (year 17)	Replacement of glazing in wooden window frames by triple HR glazing (year 0)
4	Replacement of aluminum window frames (year 17)	Replacement of aluminum window frames by aluminum frames with thermal break (year 1)
5	Replacement of large Air Handling Unit (year 3)	Replacement of Air Handling Unit with Speed controlled fans and Heat and steam recovery (year 3)
6	Replacement of small Air Handling Units (year 4)	Replacement of small Air Handling Units with speed controlled fans (year 4)
7	Replacement of pumps (year 2, 3, 6, 10)	Replacement of pumps with speed controlled pumps (year 2, 3, 6, 10)
8	Replacement of emergency lighting (year 0)	Replacement of emergency lighting by LED lighting (year 0)
9	-	Continuous monitoring and commissioning of service systems (annually)

Table 6.4 shows the initial energy prices and initial annual use of energy that represents the current energy prices of the municipality obtained from the energy invoice of the City Hall. The initial use of energy is based on an average use of energy of the past five years; due to differing weather conditions the energy use of the past years varies around this average. These energy prices are relatively low compared to non-municipal organisations.

Table 6.4 – Case specific variable values

Variable	Value
Initial electricity price	€0.11
Initial gas price	€0.50
Initial annual use of electricity	1,985,800 kWh
Initial annual use of gas	251,570 m^3

For the five economic variables shown in Table 6.5, more information is required to determine the case specific values. For the inflation rate, the maintenance price rate, the electricity price rate and the gas price rate, a rounded average was used based on statistics obtained from Statistics Netherlands (CBS). This data can be found in Appendix 8. Note that the price effects will be determined by the sum of the inflation rate and the price rates. The discount rate is determined by the case specifics: municipalities perform valuation calculations using a discount rate of 5%. This rate only discounts cash flows to cover an interest rate; no risk premium is included.

Table 6.5 – Economic parameter values

Parameter	Value
Inflation rate	2%
Maintenance price rate	0.5%
Electricity price rate	1%
Gas price rate	4%
Discount rate	5%

The time period used for this simulation is 20 years. This is considered as a reasonable time span, considering that interventions are implemented until year 10. For the interventions that are implemented this late, it means that a part of the lifecycle cost (i.e. mostly energy savings) will not be included. This time period can be seen as a piece out of the buildings lifetime in which most of the maintenance activities occur at least once.

Comments for this assessment

1) Possible energy savings that result from maintenance activities in the traditional approach are not included. This influences the outcome in favour of the new approach due to the amount of energy saved projected by the model will be higher than in reality. These energy savings that might occur when not implementing energy efficiency interventions, are for this research left out of the scope because they were too time-costly to determine and too little of absolute influence. Either an assumption can be made what effect normal maintenance will have on the energy savings, or the annual savings can be imported from excel if they can be calculated for each year.
2) For all of the interventions assessed in this case, no book value was necessary to take into account because the economic lifetime of the components already ended. In the case there was still book value left, this would have negatively influence the new scenario by resulting in higher maintenance expenditures.

6.3.2. Data input sensitivity run

To test the robustness of the outcome of the Nijmegen City Hall simulation, first the input for the MCA need to be determined. This input consists of the range and the mean values of the parameters that are considered subject to uncertainty, as described in paragraph 5.4.2. The mean values for the economic factors are the same as used in the base run (Table 6.5). The range of these parameters is set at -1% and +1%. Concerning the uncertainty on change in use of energy a -20% and +20% range was determined, based on expert input.

Table 6.6 – Parameter values and distribution used in Monte Carlo Analysis

Parameter	Distribution	Mean	Range
Inflation rate	Triangular	2	1-3%
Maintenance price rate	Triangular	0.5%	-0.5+1.5%
Electricity price rate	Triangular	1%	2-3%
Gas price rate	Triangular	4%	3-5%
Uncertainty on change in use of electricity (new scenario)	Uniform		0.8-1.2
Uncertainty on change in use of gas (new scenario)	Uniform		0.8-1.2

The MCA was performed by 1000 iterations. This means that for 1000 combinations of parameter values a simulation is performed. By the use of MCA, these combinations were automatically and randomly selected. The results can be found in the next paragraph.

6.4. Results

Given the data input as described in the previous paragraph, the base run and sensitivity run of the assessment tool are performed. Following the outcome of both runs. The User Interface output window for the base run is shown in Figure 5.6 on page 41. The entire data set representing the outcome of the calculation can be found in Appendix 8. The following paragraph comprehensively mentions and explains the model base run and sensitivity analysis outcome, followed by a brief expert interview feedback report.

6.4.1. Outcome

The assessment tool shows that over a period of 20 years the Net Present Value (NPV) of the new scenario is higher than the NPV of the base scenario, while saving 25% on the absolute use of energy and lowering the carbon emission with 20%. This means that for the City Hall case within the set assessment time period, maintenance activities can cost effectively contribute to increasing energy efficiency and lowering energy consumption. Following an explanation on the simulation outcome that leads to the aforementioned conclusion.

Main results

Figure 6.1 graphically shows the annual energy and maintenance expenditures for both scenarios. Clearly visible is the difference between in the two scenarios in the first years that can be declared by the additional maintenance expenditures made to implement the energy efficiency interventions. Note that from year 5 onwards, the energy and maintenance expenditures are permanently lower for the base scenario than for the new scenario. The large peak in the base scenario in year 17 is caused by replacement activities scheduled for window frames and glazing. In the new scenario, replacement of these components takes place in year 0 and 1. Note that due to the increase in maintenance price, the peak in year 17 is relatively large.

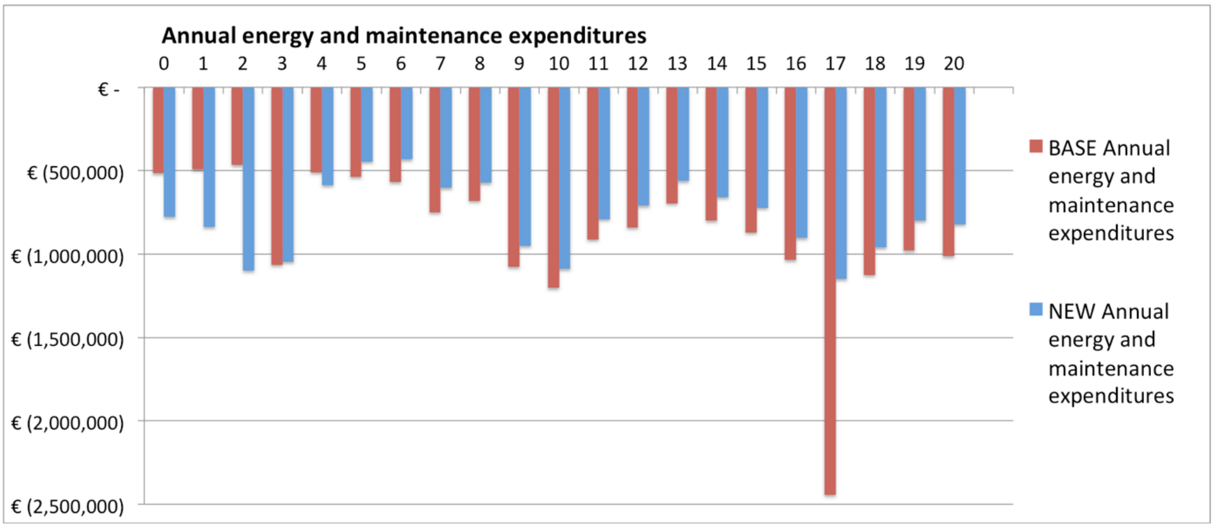


Figure 6.1 – Graph of simulation results: the annual energy and maintenance expenditures

The NPV of the energy and maintenance expenditures is shown in Figure 6.2. This graph is a result of discounting the annual energy and maintenance expenditures (i.e. cash flows) that are shown in the previous graph back to Present Value. The graph shows that the NPV of the new scenario is higher than the NPV of the base scenario over a period of 20 years. The difference in expenditures in year 18 contributes to the NPV of the base scenario to drop and cross with the NPV of the new scenario.

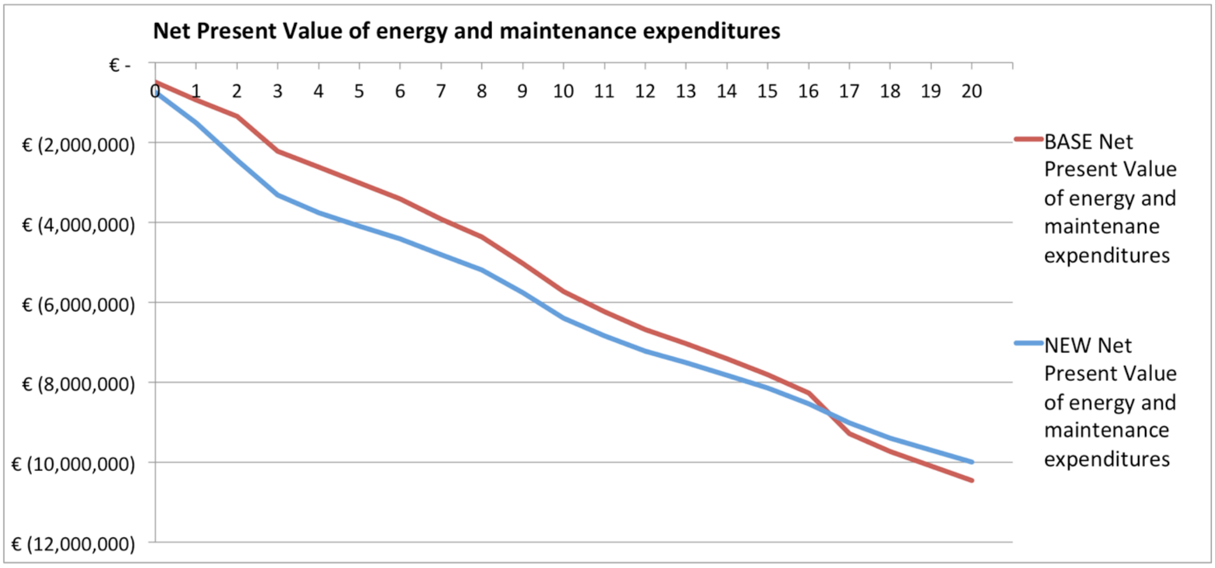


Figure 6.2 – Graph of simulation results: NPV of energy and maintenance expenditures

The numeral results of the NPV of both scenarios can be seen in Table 6.7. After a period of 10 years, the NPV of the base scenario is higher. This is not surprising, considering that additional maintenance expenditures are done in the first years and energy expenditures will be saved from the moment of implementation on. The difference between the NPV of the two scenarios after 20 years is 5%.

Table 6.7 – Simulation results: NPV of energy and maintenance expenditures

	Base	New
After 10 years	(€5,725,932)	(€6,403,014)
After 20 years	(€10,457,305)	(€9,995,750)

If the NPV over 20 years are calculated back to the price per m^2 per year, one can find the figures shown in Table 6.8. These numbers implicate that for this case over a period of 20 years, by spending two euro more on maintenance activities, four euro is saved on the energy bill. This together results in savings of two euro on total energy and maintenance expenditures per m^2 per year.

Table 6.8 – Average expenditures per m^2 per year

	Base	New
Average maintenance expenditures in euro/year/m^2	€14,-	€16,-
Average energy expenditures in euro/year/m^2	€21,-	€17,-
Average total energy and maintenance expenditures in euro/year/m^2	**€35,-**	**€33,-**

The difference in energy expenditures between the base and new scenario are logically a result of energy savings. Figure 6.3 shows the 25% energy saving that results from the energy efficient maintenance activities schedules in the new scenario, from year 5 onwards. These savings translate a large drop in carbon emission as can be seen in the graph and in Table 6.9 that represents a decrease of 20%. Note that in this case study no energy savings were included for the base scenario. This causes the constant level of energy savings (i.e. 0%) and carbon emission.

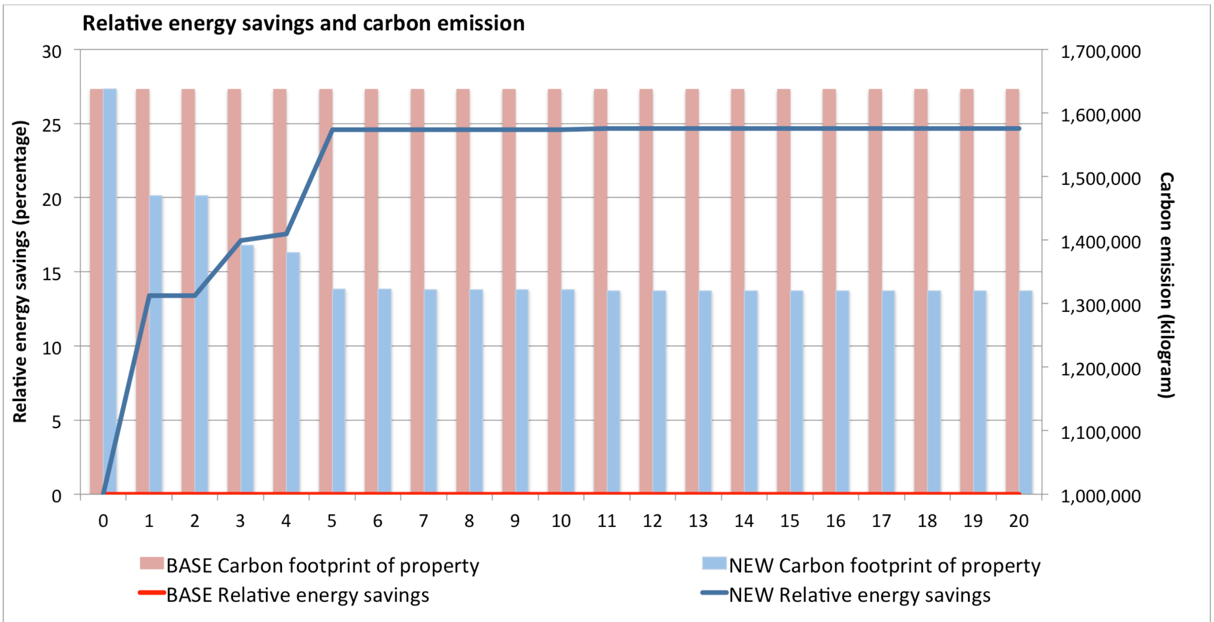


Figure 6.3 – Graph of simulation results: relative energy savings and carbon emission

Table 6.9 – Simulation results: energy savings and carbon emission

	Base	New
Annual relative energy savings		
At t=20	0%	25%
Carbon emission		
At t=20	1,637,497 kg	1,320,291 kg

Energy efficiency interventions

The main difference between the two simulated scenarios is that the new scenario includes maintenance expenditures resulting from the implementation of energy efficiency interventions. This means that the difference between the base and new scenario in NPV of the energy and maintenance expenditures is the value of the energy efficiency interventions. Figure 6.4 and Table 6.10 show this NPV, including the NPV of the additional maintenance expenditures and the NPV of the energy expenditure savings. One can see that in year 16, the NPV becomes positive. This means that the sum of discounted benefits is higher than the sum of discounted costs.

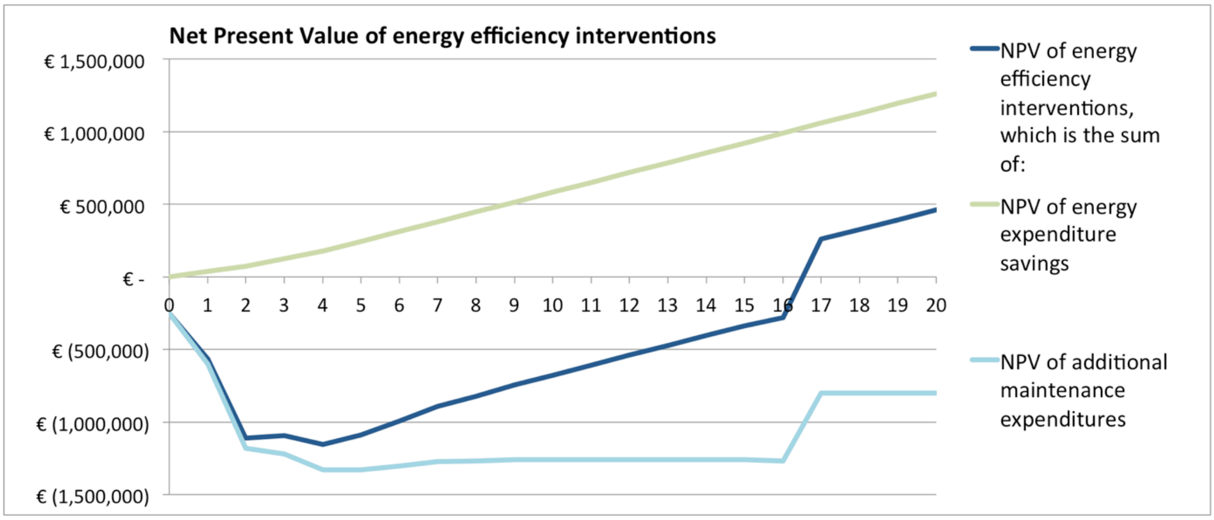


Figure 6.4 – Graph of simulation results: NPV of the energy efficiency interventions

Table 6.10 – Simulation results: NPV of the energy efficiency interventions

Parameter	Outcome (negative value)
Net present value of additional maintenance expenditures	
After 10 years	(€1,260,412)
After 20 years	(€800,367)
Net present value of energy expenditure savings	
After 10 years	€583,330
After 20 years	€1,261,922
Net present value of energy efficiency interventions (sum of the two above NPVs)	
After 10 years	(€677,082)
After 20 years	€461,555

Monte Carlo sensitivity analysis

Based on the pre-sets discussed in paragraph 6.3.2, a sensitivity test was performed. According to Sterman, a sensitivity analysis requires much more than varying parameters; it tests whether the conclusions that will be deducted from the model outcome will change when uncertainties are incorporated (Sterman 2000). For this research, the following questions are of importance:

1) Does the sensitivity run create substantial differences in the NPV of the base scenario and the new scenario?
2) Will decision making differ, given these differences in the outcome?

Appendix 8 shows the sensitivity output graphs for the MCA, translated into a boxplot as shown in Figure 6.5. Regarding the base scenario, analysis shows that the maximum and minimum NPV's generated by the MCA differ -13% and +13% to the base run outcome. For the new scenario, the maximum and minimum differ -10% and +10%. For none of the sensitivity simulation runs the NPV of the energy and maintenance expenditures is higher in the base scenario than in the new scenario. This means, that within the boundaries of the sensitivity run, the outcome would not result in other decision making if the NPV over 20 years is considered as the most important variable.

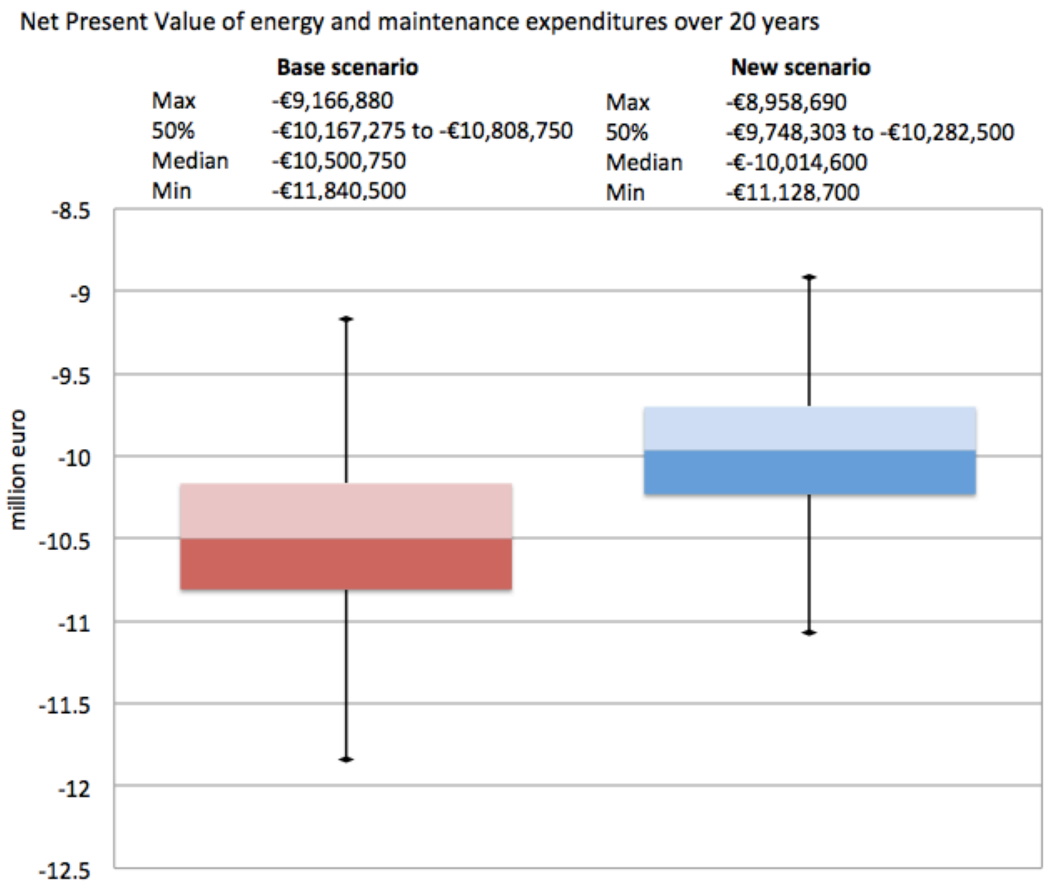


Figure 6.5 – Boxplot of the Monte Carlo Analysis outcome

The above boxplot graphically depicts the data outcome of the MCA by showing the data set quartiles. The spacing between the different parts of the box and tail help understanding the spread of the MCA outcome. The boxes indicate the outcome of 50% of the iterations in which the middle represent the outcome median. The whiskers (i.e. the black lines) represent the outer 25% of the outcome on the lower and upper value of the box. The boxplot shows that the spread of the results in the base scenario is wider than in the new scenario. This means that the uncertainty of the NPV of energy and maintenance expenditures over 20 years for this case is higher in the base scenario; this means that with pursuing the old maintenance strategy, for this specific case the spread of uncertainty on future cost is 23% larger than when adopting the energy efficient strategy. The difference in spread results from the difference in energy use in the base and new scenario.

6.5. Expert feedback

Experts in the maintenance advisory sector and municipal sector were consulted by presenting them the assessment tool, with the aim to verify the tool and validate whether the tool can provide insights useful to support decision making. Besides that, the experts were asked to interpret the case study results.

The following conclusions can be derived from the interviews regarding the assessment tool:

The main aim of the assessment tool is to support organisations in assessing multiple maintenance strategies so a decision can be made on what maintenance strategy to follow. Based on the output generated by the assessment tool, experts agree on the conclusion that the tool user is provided with the right information to support decision making. The decision itself is dependent on the objectives and financing possibilities of the organisation. Although payback calculations of single interventions are currently the main method to assess opportunities, the use of the NPV calculations provides useful new insights. The performance indicators that are used in the model (i.e. money, energy savings and carbon footprint) are the most important indicators that are used within municipalities at this moment. However, the experts are not familiar with the assessment of a maintenance scenario in which total energy and maintenance expenditures are examined. Normally, either singularly the energy savings and additional maintenance or investment cost are included when assessing one or more energy efficiency interventions, or singularly maintenance costs are prognosed. Besides that, economic factors are often left out of context due to the uncertainty of these factors. However, the assumptions regarding the economic factors for this research are considered sound. Lastly, System Dynamics and Vensim are outside the academic field unknown methods and software packages. Therefore, the User Interface is helpful in guiding the tool user through the model.

The following conclusions can be derived from the interviews regarding the results of the City Hall case study:

Although the total expenditures in the new scenario are lower than the total expenditures in the base scenario, experts are inclined to only focus on the additional maintenance expenditures. “The energy bill will be paid anyway”. As a result of the lack of integrally assessing energy and maintenance expenditures, the consulted experts are not aware of the proportion energy versus maintenance expenditures per m^2. They notice that energy expenditure per m^2 are higher than maintenance cost and that with spending slightly more resources on building maintenance, the energy expenditures and above all the total expenditures can decrease. This specific case study is characterized by a building with a low Energy Label (G) and thus relatively a large improvement potential, and on the other hand by an organisation for which the unit price for energy is very low what lowers the profitability of expenditures. The main method when it comes to energy efficiency improvements is to assess the payback period. This can also be seen considering this case study outcome, where experts are interested in the payback time of single interventions instead of focusing on the total cost over a period of time. Appealing outcome of the sensitivity analysis is that by additional maintenance expenditures, the uncertainty on total cost lowers. All municipal experts mention that the split incentive, which is present for several buildings in the municipal portfolio, troubles the decision-making regarding widening the maintenance budget. Even for buildings that are occupied by the municipality itself, this barrier is present. Especially in today's economic situation, additional expenditure needs to be societally substantiated and long-term benefits are often out of consideration for municipal politicians. Overall, for this specific case the difference between the two scenarios regarding the financial effects is not of a size that will immediately lead actors choosing the new scenario, regardless the energy and carbon emission saving it goes accompanied by. However, if organisations have the intention to reduce energy consumption, this integral approach can be a sustainable way of achieving reduction objectives.

7. Conclusion and discussion

In the introduction of this research report, three research questions were posed. In this paragraph the gained insights regarding the research questions are discussed, followed by the identified research limitations, implications and recommendations for future research.

7.1. Conclusion

RQ1: How can building maintenance and repair activities improve property energy efficiency?

Building maintenance and repair (BMR) can improve the property energy efficiency if its management objective is extended. Additional to the preservation of the technical functionality of all service systems and building components, BMR should also focus on the optimisation of energy efficiency. The following activities should be a part of BMR in which energy efficiency improvement interventions are embedded:

1) Preventative maintenance is scheduled and executed to ensure technical and economic lifetime of service systems and building envelope components, and to optimise the energy efficiency of both systems and components.
2) Replacement of systems and components by an energy efficient solution is done when or before the technical lifetime of a system or component has ended.
3) Placement of new systems and components including insulation is performed increment to scheduled maintenance activities if this can improve energy efficiency.

The above maintenance activities need to be (re)scheduled in maintenance schedules. The complete procedure to schedule interventions within maintenance activities consists of multiple steps, preceded by a strategic decision that initiates the procedure. The following steps are organisational exploration, objective setting, development of scenarios, assessment of scenarios, decision-making, planning and execution and evaluation.

RQ2: How can energy efficiency improvement opportunities be identified?

The identification of opportunities comprises the identification of technical solutions that can eliminate energy inefficiencies. This can be done by the following three steps: 1) identifying energy inefficiencies, 2) identifying energy inefficient components and 3) determining the technical solutions that can eliminate these inefficiencies. Firstly, gaining insight in the energy performance of property by measuring energy use and using comparable information such as benchmarks helps examining whether inefficiencies are present. Besides that, continuous monitoring and the use of sustainability ratings such as the Energy Label can indicate improvement possibilities. However, having found energy inefficiencies does not directly indicate what the source of inefficiency is. Therefore, secondly, inspection methodologies or examining the building characteristics should indicate what components cause the energy inefficiencies. Thirdly, for these components, solutions can be identified. The quality or completeness of the identification step largely depends on the quality and quantity of information that is available to the building operator. A lack of insight in the technical performance of property and in the energy performance hampers the identification process. Besides that, standardised improvement lists are often used to determine technical solutions. However, these lists do no not always provide sufficient or accurate solutions. Ideally, identifying solutions is supported by insight in the actual energy use, based on detailed property information and resulting in tailor-made solutions.

RQ3: How can identified improvement opportunities be assessed?

The assessment of technical solutions that can improve energy efficiency in current practice often consists solely of financial valuation by determining the simple payback period of energy savings regarding the investment cost. Besides using the payback period as a valuation method ignores the time-value of money and energy cost savings that occur after the payback period, there are more benefits than financial ones. A reduction in carbon footprint and therewith a lower environmental impact, plus improved sustainability ratings are other important benefits. Furthermore, energy efficient technical solutions most likely positively influence the indoor environmental quality and consequently occupants' productivity. These benefits all influence the corporate image. The use of Life Cycle Costing Analysis by using the discounted cash flow method calculating all cash flows during a components lifetime to the Net Present Value is a sophisticated valuation method. Considering that energy efficiency improvements are an increment to maintenance activities that are already scheduled, replacement of a component by an energy efficient solution can be assessed by calculating the Net Present Value of all incremental costs or income regarding the present building component. A positive Net Present Value indicates a higher value for the energy efficient solution what means that implementation of this solution will, over its total lifetime, lead to cost savings.

The development of a dynamic assessment tool aims helping organisations in assessing energy efficient maintenance scenarios that include multiple energy efficiency interventions as a part of other maintenance activities. The tool provides organisations a method with which multiple maintenance scenarios can be analysed. By entering expected annual maintenance expenditures and energy savings, the model will generate Net Present Value of the scenarios while taking future price increases into account. Besides this, projected energy saving percentages and carbon emission are calculated. Parameters concerning maintenance and energy price increases can be manually changed and the discount rate can be set according to the organisations financial criteria. A User Interface guides the tool user through the required steps to generate the scenario outcome. The model is tested using a case study into the City Hall of Nijmegen, the Netherlands. By entering two scenarios into the assessment tool, comprising the existing maintenance plan as a base scenario and a new adapted maintenance plan including nine energy efficiency interventions as a second scenario, expenditures where considered over a time period of 20 years. This resulted in the Net Present Value of the new scenario 5% higher in value than the old maintenance plan, while energy consumption decreases 25% and carbon emission 20%. This means that while spending less money on energy and maintenance, energy consumption is reduced. The tool was verified by expert interviews in the municipal sector and consultancy sector.

Main research question: How can the opportunities to improve energy efficiency within maintenance activities of existing non-residential property be exploited?

This research has resulted in determining that maintenance activities can contribute to energy efficiency by embedding energy improving interventions within the existing maintenance planning. The steps to examine specific energy efficient solutions comprise of finding energy inefficiencies, determining inefficient systems or components and consequently technical interventions. Possible assessment criteria are identified of which financial assessment criteria are discussed in more detail, leading to the advise to use Life Cycle Cost Analysis and the discounted cash flow method to evaluate single improvement opportunities. Lastly, an assessment tool is provided that supports the assessment of multiple improvement interventions as a part of a complete maintenance schedule. These research results provide useful guidance in exploiting opportunities within maintenance activities to reduce energy consumption.

7.2. Discussion

7.2.1. Practical implications and recommendations

The findings of this study have a number of important implications for future practice. Two courses of action are suggested to all parties concerned with corporate real estate management, and specific courses of action are suggested to corporate organisations, advisory companies and national government (i.e. main stakeholders of the research problem).

Firstly, organisations concerned with property management are recommended to gain insight on the actual energy consumption. Not only does insight in the data situation create awareness on the amount of energy use and provide solid ground to base decisions on, data is also a means of communication between management. Besides that, with this insight in energy use, savings can be monitored and this data can be used to communicate within and outside of the organisation. At this moment, apart from invoice checking, there is often a lack of real time insight in the energy use. Insight can be gained by installing ‘smart meters’ (Dutch: slimme meters). These meters are at this moment becoming more common in all buildings. Preferably multiple meters are being installed for properties that are of considerable size, so energy use can be assigned to specific parts of the property. A crucial step is ensuring that an employee or automatised system gathers the data that is generated by the smart meters. Furthermore, within organisations is recommended to realise a central place where this data can be accessed.

Secondly, concerning the financial valuation of improvement possibilities two implications can be identified. 1) The use of the simple payback period calculation to as a means to assess the profitability of single improvements should be reconsidered. The use of life cycle costing analysis provides a more realistic overview and is therefore recommended. 2) Organisations are, besides individual assessment of improvements, recommended to assess a combination of improvements as a part of a complete maintenance scenario and while taking future uncertainties into account. This method of assessment is a more holistic approach and aids decision-making by providing a complete overview of the range of costs. Tools, such as the assessment tool developed in this research, can help organisations in performing this more complex assessment. Essential is the incorporation of total energy use and costs in financial overviews. This will require a shift in thinking due to energy cost generally being accepted as overhead cost instead of cost that can be actively managed.

Following implications that arise from the research results and are applicable to property management within organisations. The case study has shown that within maintenance activities cost effectively energy reductions can be realised. This implicates that organisations should consider whether for their own property, likewise results are possible. Depending on the specific organisation, this can be done either by using in-house expertise or involving external expertise. For both approaches, the quality of property information and knowledge on energy efficient technologies should be ensured to identify tailor-made improvement activities. Many organisations have the strategic aim to reduce energy, although these aims are not yet translated into effective practical solutions. Embedding energy interventions within existing processes such as property maintenance is proposed as a sustainable solution to realise saving objectives.

For consultancy companies there is an important role when it comes to aspects concerning sustainability such as energy reduction. Many organisations heavily rely on consulting expertise. Consultancy companies can support organisations in exploiting opportunities within property maintenance by support in gaining insight in energy inefficiencies and by providing tailor-made advice. More importantly, they can support determining where specific difficulties are expected in the improvement process and use practical experiences to solve these difficulties. Consultancy companies are favoured with the expertise gained by having advised multiple clients. Besides clients that are willing to seize improvement opportunities, several clients might not yet see the added value of paying attention to energy reduction and advise is asked concerning other property management aspects. Concerning this type of client, advisory companies are requested to take its share of societal responsibility and entice the client by giving insight in possible benefits. One example is to provide a client with one or more additional maintenance scenarios regardless that a consultant is only requested to develop a traditional maintenance schedule. Although this is more time-consuming, it can in the end result in cost savings for the client and added value regarding the consultant's service.

Lastly, one implication is given that concerns government. National government has the power to introduce legal obligations such as for example the Environmental Permit that forces organisations to implement all energy efficiency interventions with a payback period below five years. However, many practical barriers are faced in the improvement process what causes organisations not being compliant with this end-result directed legislation. Rather, government should focus on compelling conditions that contribute to the improvement process. One specific aim could be to oblige organisations to have insight in their monthly energy consumption.

7.2.2. Limitations and directions for further research

The following limitations were identified that influence the results and generalizability of the research.

First of all, the assessment tool is supported by System Dynamics and developed using Vensim software. However, this is not the only method or software package that can aid in developing this type of assessment tool. No other methods were tested to develop the assessment tool so no benefits and disadvantages regarding other methods have been examined. This indicates that other methods possibly can provide a more accurate or easier to use assessment tool. Besides this, the assessment tool is verified by the performance of a single case study. Although the case study proves the functionality of the assessment tool for this specific case, multiple case studies should be performed to identify if the tool is actually robust. A suggestion for further research is to perform more case studies within various sectors to test the tool. The case study was not aimed at gaining generalizable data regarding maintenance cost or energy savings. However, the tool can be used to gather this data. If future research focuses, besides the verification of the tool, on performing case studies with a large sample size (i.e. >10), there can be examined whether energy can be reduced cost-effectively by embedding energy efficiency interventions within maintenance activities.

Secondly, expert interviews were performed as a means to gather data in the exploration phase and to verify the assessment tool and case study data. Exploratory interviews were performed by consulting multiple experts with various backgrounds, with the aim to cover multiple views and assess broad experience on the topics of interest. The data that results from interviews with the aim to verify the assessment tool was gathered from a single point of contact; within the municipalities single interviewees were consulted what holds the limitation that the results are more difficult to generalize. On top of this, the technique of interview is not free from bias, especially if the interviewer is one single researcher. Ideally, the research is supported by the use of a statistical data collection method. Future research can therefore for example use survey research to verify the assessment tool to eliminate the drawbacks of interview research.

Following other topics suggested for further research based on the findings of this research.

1) This research pointed out that energy reduction of non-residential property goes accompanied by multiple benefits of which not all are included in the assessment tool. Further research could examine how organisations value the impacts that are now not included in the assessment tool, such as indoor environmental climate. If high value is seen in the assessment of these other benefits, the assessment tool can be extended.
2) The current research was not designed to evaluate for which real estate sector the new approach to building maintenance is the most suitable or will lead to the highest benefits. A suggestion for further research is to investigate building operators views on the energy efficient maintenance approach by the means of survey research.

References

- Agentschap NL, 2013a. *Enorme energiebesparing mogelijk in gemeentelijk vastgoed*, The Netherlands.
- Agentschap NL, 2012. *Infoblad Trias Energetica en Energieneutraal Bouwen*, Utrecht, the Netherlands.
- Agentschap NL, 2013b. *Leidraad verduurzamen meerjaren onderhoud van gemeentelijk vastgoed*, Utrecht, the Netherlands.
- Agentschap NL, 2011a. *Resultatenbrochure convenanten Meerjarenafspraken energie-efficientie 2011*, The Netherlands.
- Agentschap NL, 2011b. *Succesfactoren voor energiezuinige renovatie- en nieuwbouwprojecten*,
- Agentschap NL, 2010. *Verdienen met duurzaam onderhoud*, Utrecht, the Netherlands.
- Alanne, K., 2004. Selection of renovation actions using multi-criteria “knapsack” model. *Automation in Construction*, 13(3), pp.377–391.
- Augenbroe, G., Castro, D. & Ramkrishnan, K., 2009. Decision model for energy performance improvements in existing buildings. *Journal of Engineering, Design and Technology*, 7(1), pp.21–36.
- Augenbroe, G. & Park, C.S., 2005. Quantification methods of technical building performance. *Building Research & Information*, 33(2), pp.159–172.
- Aune, M., Berker, T. & Bye, R., 2009. The missing link which was already there: Building operators and energy management in non-residential buildings. *Facilities*, 27(1/2), pp.44–55.
- Avis, M., Gibsen, V. & Watts, J., 1990. Managing operational property assets. *Facilities*, 8(5), pp.11–16.
- Bakker, J., Remmers, J. & Verstappen, R., 2012. *Energiebesparing in Nederlandse kantoren bij beursgenoteerde bedrijven*, Utrecht, the Netherlands.
- Bon, R., Mcmahan, J.F. & Carder, P., 1994. Measurement: From Theory to Management Practice. *Facilities*, 12(12), pp.18–24.
- Bonde, M., 2012. Difficulties in changing existing leases – one explanation of the “energy paradox”? *Journal of Corporate Real Estate*, 14(1), pp.63–76.
- Brealey, R.A., Myers, S.C. & Allen, F., 2011. *Principles of Corporate Finance* 10th ed., New York, USA: McGraw-Hill.
- Carbon Trust, 2010. *Energy Management*, London, United Kingdom.
- Commission of the European Communities, 2007. *Limiting Global Climate Change*, Brussels, Belgium.
- Corporate Knight, 2013. Global 100 financial performance. *May 31*. Available at: http://www.global100.org/global-100-monthly-update.html [Accessed June 3, 2013].
- Crosbie, T., Dawood, N. & Dean, J., 2010. Energy profiling in the life-cycle assessment of buildings. *Management of Environmental Quality: An International Journal*, 21(1), pp.20–31.
- Daniels, B.W. & Farla, J.C.M., 2006. *Optiedocument energie en emissies 2010 / 2020*, Bilthoven, the Netherlands.
- DHV, 2011. *Duurzaamheidsmaatregelen*, Amersfoort, the Netherlands.
- Dobbs, R., Oppenheim, J. & Thompson, F., 2012. Mobilizing for a resource revolution. *McKinsey Quarterly*, pp.1–15.
- Doorewaard, H. & Verschuren, P., 2010. *Designing a Research Project*, The Hague: Eleven International Publishing.

- Edwards, V. & Ellison, L., 2008. *Corporate Property Management* 3rd ed., Oxford, United Kingdom: Blackwell Publishing.
- European Commission, 2011. *Energie-efficientieplan 2011*, Brussel, Belgium.
- Gemeente Amsterdam, 2011. *Energiemonitoring en dan? Energiereductie!*,
- Haasl, T. & Sharp, T., 1999. *A Practical Guide for Commissioning Existing Buildings*, Tennessee.
- Van Hauwermeiren, M., Vose, D. & Vanden Bossche, S., 2012. *A compendium of distributions [ebook]* 2nd ed., Ghent, Belgium: Vose Software.
- Ten Have, F., Hoevers, B. & Huisman, R., 2012. *G25-gemeenten aan het woord: Verduurzaming gemeentelijk vastgoed*, Amsterdam, the Netherlands.
- Herik, P. van den et al., 2013. *Leidraad Prestatiecontracten*, Utrecht, the Netherlands.
- Hertzsch, E., Heywood, C. & Piechowski, M., 2012. A methodology for evaluating energy efficient office refurbishments as life cycle investments. *International Journal of Energy Sector Management*, 6(2), pp.189–212.
- Hiang, L.K. & Ooi, J.T.L., 2000. Current issues in strategic corporate real estate asset analysis and management. *Journal of Corporate Real Estate*, 2(3), pp.240–249.
- Högberg, L., 2011. *Incentives for energy efficiency measures in post-war multi-family dwellings*. Royal Institute of Technology Kungliga Tekniska Hogskolan.
- ISO, 2013. Management system standards. Available at: http://www.iso.org/iso/home/standards/management-standards.htm [Accessed May 3, 2013].
- ISSO Kennisinstituut voor de Installatiesector, 2011. *Energieprestatie Advies Utiliteitsgebouwen ISO 75.1 75.2 and 75.3*, Rotterdam, The Netherlands.
- Jaffe, A.B. & Stavins, R.N., 1994a. Energy-efficiency investment and public policu. *The Energy Journal*, 15(2), pp.43–65.
- Jaffe, A.B. & Stavins, R.N., 1994b. The energy-efficiency gap What does it mean? *Energy Policy*, 22(10), pp.804–810.
- Juan, Y.-K., Gao, P. & Wang, J., 2010. A hybrid decision support system for sustainable office building renovation and energy performance improvement. *Energy and Buildings*, 42(3), pp.290–297.
- Junghans, A., 2013. Decision support model for energy-efficient improvement of entire building stocks. *Facilities*, 31(3), pp.173–184.
- Junnila, S., 2007. The potential effect of end-users on energy conservation in office buildings. *Facilities*, 25(7/8), pp.329–339.
- De Kopgroep Maatschappelijk Vastgoed, 2008. *Zo rekenen we aan maatschappelijk vastgoed*,
- Kulakowski, S.L., 1999. *Large organizations' investments in energy-efficient building retrofits*, Berkeley, United States of America.
- Maassen, W., 2013. *Toekomstgericht renoveren op basis van scenario's [presentatie]*, Eindhoven, The Netherlands.
- Mansfield, J.R., 2009. The valuation of sustainable freehold property: a CRE perspective. *Journal of Corporate Real Estate*, 11(2), pp.91–105.
- Marino, A. et al., 2011. A snapshot of the European energy service market in 2010 and policy recommendations to foster a further market development. *Energy Policy*, 39(10), pp.6190–6198.

- Martinaitis, V., Kazakevičius, E. & Vitkauskas, A., 2007. A two-factor method for appraising building renovation and energy efficiency improvement projects. *Energy Policy*, 35(1), pp.192–201.
- Menkveld, M. & Van Den Wijngaart, R.A., 2007. *Verkenning potentieel en kosten van klimaat en energiemaatregelen voor Schoon en Zuinig*, The Netherlands.
- Metz, B. et al., 2007. *Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, United Kingdom and New York, USA.
- Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2011. *Plan van Aanpak Energiebesparing Gebouwde Omgeving*,
- MVO Platform, 2012. *CSR Frame of Reference*, Amsterdam, the Netherlands.
- Nederlands Normalisatie-instituut (NEN), 2011. *NEN-EN-ISO 50001 Energy Management Systems*, Delft, the Netherlands.
- NFC Index, 2013. NFC Index webpage. Available at: www.nfcindex.nl [Accessed April 6, 2013].
- Pérez-Lombard, L., Ortiz, J. & Pout, C., 2008. A review on buildings energy consumption information. *Energy and Buildings*, 40(3), pp.394–398.
- Planbureau voor de Leefomgeving (PBL), 2012. *Balans van de leefomgeving 2012*, The Hague, The Netherlands.
- Rijksgebouwendienst, 2012. *Handboek Rgd-BOEI-inspecties*,
- Rijksgebouwendienst (RGD), 2010. *Factsheet Functioneel Controleren Inregelen en Beproeven (FCIB)*, The Hague, The Netherlands.
- Rooijers, F.J., Leguijt, C. & Groot, M.I., 2010. *Halvering CO2-emissie in de Gebouwde Omgeving*, Delft.
- Royal HaskoningDHV, 2013. *Enhancing Assets Together*, Amersfoort, the Netherlands.
- Royal HaskoningDHV, 2012. *Sustainability Business Line Buildings*, Amersfoort, the Netherlands.
- Schleich, J., 2009. Barriers to energy efficiency: A comparison across the German commercial and services sector. *Ecological Economics*, 68(7), pp.2150–2159.
- Schneider, H. & Steenbergen, P., 2010. *Marktstudie CO2 - besparingpotentieel ESCo's in utiliteitsbouw*, Delft, the Netherlands.
- Schwartz, P., 1996. *The Art of the Long View: Planning for the Future in an Uncertain World*, London: Currency Doubleday.
- SenterNovem, 2013a. Energie en Gebouwde Omgeving Energiecijfers. Available at: www.senternovem.databank.nl [Accessed July 8, 2013].
- SenterNovem, 2013b. SenterNovem omrekening energie eenheden. Available at: http://www.senternovem.nl/kompas/omrekentool/calculator.htm [Accessed July 3, 2013].
- Shah, S., 2007. *Sustainable Practice for the Facilities Manager*, Blackwell Publishing.
- Van Soest, D.P. & Bulte, E.H., 2001. Does the Energy-Efficiency Paradox Exist? Technological Progress and Uncertainty. *Environmental and Resource Economics*, (1991), pp.101–112.
- Stanford, H.W., 2010. *Effective Building Maintenance - Protection of Capital Assets*, The Fairmont Press, Inc.
- Statistics Netherlands (CBS), 2013. Statline. Available at: http://statline.cbs.nl/StatWeb/?LA=nl [Accessed July 23, 2013].
- Sterman, J., 1992. *System Dynamics Modeling for Project Management*, Cambridge, USA.

- Sterman, J., 2000. *Systems Thinking and Modeling for a Complex World*, Irwin McGraw-Hill.
- Stern, 2006. *Stern Review: The Economics of Climate Change Executive Summary*,
- Strachan, M. & Banfill, P., 2012. Decision support tools in energy-led, non-domestic building refurbishment: Towards a generic model for property professionals. *Facilities*, 30(9/10), pp.374–395.
- Van Strien, P., 1997. Towards a methodology of psychological practice: the regulative cycle. *Theory & Psychology*, 7(5), pp.180–201.
- United Nations, 2009. Copenhagen Accord. Available at: http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf [Accessed March 8, 2013].
- United Nations, 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. Available at: http://unfccc.int/resource/docs/convkp/kpeng.pdf [Accessed March 8, 2013].
- United Nations Environment Programme (UNEP), 2009. *Buildings and climate change*, Paris, France.
- Verdonk, M. & Wetzels, W., 2012. *Referentieraming energie en emissies: actualisatie 2012*, The Hague, The Netherlands.
- Wargocki, P. & Seppanen, O., 2006. *Indoor climate and productivity in offices : how to integrate productivity in life-cycle cost analysis of building services*, Brussel, Belgium: REHVA.
- Watson, D. & Head, A., 2010. *Corporate Finance* Fifth., Essex, England: Prentice Hall.
- Yik, F.W.H., Lee, W.L. & Ng, C.K., 2002. Building energy efficiency and the remuneration of operation and maintenance personnel. *Facilities*, 20(13/14), pp.406–413.

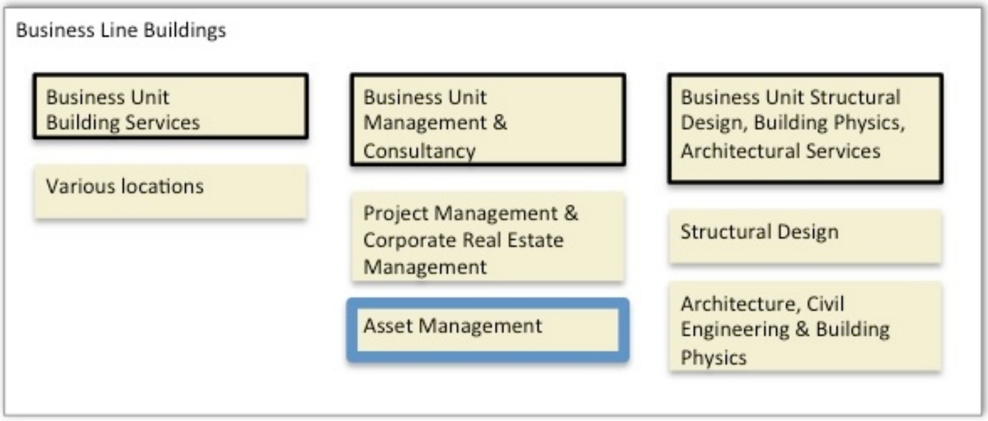
Appendices

Appendix 1 Royal HaskoningDHV

Asset Management within Royal HaskoningDHV

This research is supported with an internship within the advisory group Asset Management within the business line Buildings of Royal HaskoningDHV. Royal HaskoningDHV defines Asset Management as the coordinated activities of an organisation to realise value from assets. It is about using assets to deliver value and achieve the organisations explicit purposes; this includes techniques for converting the organisational aims into practical implications for choosing, acquiring, utilising and maintaining the assets to deliver those aims (Royal HaskoningDHV 2013).

To better understand the position and activities of the advisory group Asset Management, the organisational structure is shown in Appendix figure 1. The figure shows the structure of one of the ten business lines: Buildings. Asset Management is organizationally one of the advisory groups within the business unit Management & Consultancy.



Appendix figure 1 – Organisational chart: Business Line Buildings within Royal HaskoningDHV (adapted from the RHDHV chart)

The groups Project Management & Corporate Real Estate Management and Asset Management operate individually, although the activities they perform do relate to each other. Project Management can be restricted to the development of new buildings whereas the Asset Management group mainly focuses on existing buildings.

Asset Management activities

The services of Asset Management are divided into three teams.

Portfolio/asset- and contract management - Advice about maintaining and management of property (portfolios) and the execution of contract management is the key element within this team. Royal HaskoningDHV adopts the role of contract advisor, performance auditor (quality assurance) or managing agent (Royal HaskoningDHV 2013). Maintenance advice includes the writing of multiple year maintenance schedules and budgeting of capital and operational expenditures. One client within this team is the municipality of Nijmegen. In Nijmegen, Royal HaskoningDHV is the managing agent and managing contractor for a portfolio existing of 600 buildings. This means that they are responsible for the technical performance and maintenance of the buildings, and that the contractors that execute the operational work are controlled. Another client is ABN AMRO bank. The goal of ABN AMRO was to improve the sustainability of their complete portfolio counting 378 offices in the

Netherlands. Royal HaskoningDHV determined the technical and financial feasibility of the proposed measures with the result that with minimum costs the sustainability profile was maximised.

Information management - The second team within Asset Management focuses on providing technical information from properties such as two and three-dimensional as-built drawings. Advising, implementing and executing are part of the activities that mostly concern operational level. An example is the mapping of the entire building portfolio of the Dutch Government Buildings Agency (Dutch: Rijksgebouwendienst).

On-site services - Offering guidance on site is the most comprehensive service within the advisory group Asset Management. Within the existing environment of the client, guidance is offered on the fields of technique, processes and finances. Functional maintenance, renovations and sustainable adjustments of existing property are examples of activities in which the consultants offer guidance. An example of a client is Douwe Egberts. Royal HaskoningDHV is on-site responsible for managing the maintenance activities of the entire property portfolio of Douwe Egberts and performs project management. This also means that the role of contract manager for the main contracting and responsibility for projects from initiative to completion is taken.

Type of clients

Royal HaskoningDHV's clients are present within various market sectors and are private as well as public organisations. Mostly, clients are property owner as well as the property user; incidentally a real estate investor asks for consultation. In other words, the team Asset Management mostly advises Corporate Real Estate Managers. Clients can be found within the following sectors: education, municipalities, financial institutions, industry and healthcare institutions.

Revenue is produced from around 300 clients, of which the ten largest clients (3%) are responsible for 72% of the revenue and the top three of 42%. Appendix figure 2 shows approximately the proportion of the different activities regarding the total revenue.

Appendix figure 2 – Key activities of the Asset Management group against revenue proportion (RHDHV, 2013)

Sustainability

On a strategic and visionary level, Royal HaskoningDHV actively pursues sustainable corporate strategies. "Sustainability is at the centre of our ambitious Corporate Responsibility agenda which demonstrates an absolute commitment throughout our operations to work for the good of society, our clients and our people" and "As leaders in sustainability and innovation, we are deeply committed to continuous improvement, business integrity and sustainable development, and work with our clients, stakeholders and communities to enhance society together" (RHDHV website).

Within the client portfolio of Asset Management, the request for sustainability is growing. However, the traditional approach of managing buildings (operational level) is to keep the performance of a building on the same level. This conservative approach can also be seen in the attitude of a part of the RHDHV employees. There are a few examples of projects within the Asset Management group where the sustainable performance of a building or portfolio was leading such as the municipal real estate portfolio of Nijmegen and also the portfolio of ABN AMRO offices as mentioned above. Specific knowledge within Royal HaskoningDHV on energy efficiency can be found within the Building Services groups and Building Physics group. These experts see many opportunities within current property management to easily improve the efficiency of energy.

Trends

Since the merge of Royal Haskoning and DHV innovation receives more attention. Because the difficult economic situation in the Netherlands that can be seen reflected in the declining level of cliental requests towards advisory companies in the built environment, the importance of improving competitive advantage by for example innovative solutions is noticed. Several knowledge groups and other working groups within Royal HaskoningDHV investigate the possibilities of adapting their current products and services to address new clients or add value to current clients. Besides the activities performed in the advisory groups there is a business line overlapping group of employees that focuses on new business developments in different market sectors. At the moment the activities of Asset Management focus on questions on strategic, tactic as well as performing operational questions. The tendency is to move upwards in the levels on which advice is given and focus on where value can be added to the client compared to other companies. However, the largest part of revenue results from services on operational level. It must be said that the fact that employees have knowledge about activities on strategic, tactical and operational level highly contributes to the overall value proposition of the Asset Management group. Within the business line buildings, the changing focus from new buildings towards existing buildings is noticed; the amount of new building projects dramatically decreased because of the financial crisis. This means that not only for Asset Management, but also for Project Management & CREM advice on existing buildings becomes of higher importance.

Appendix 2 Energy Management Systems: Carbon Trust and ISO-NEN-EN

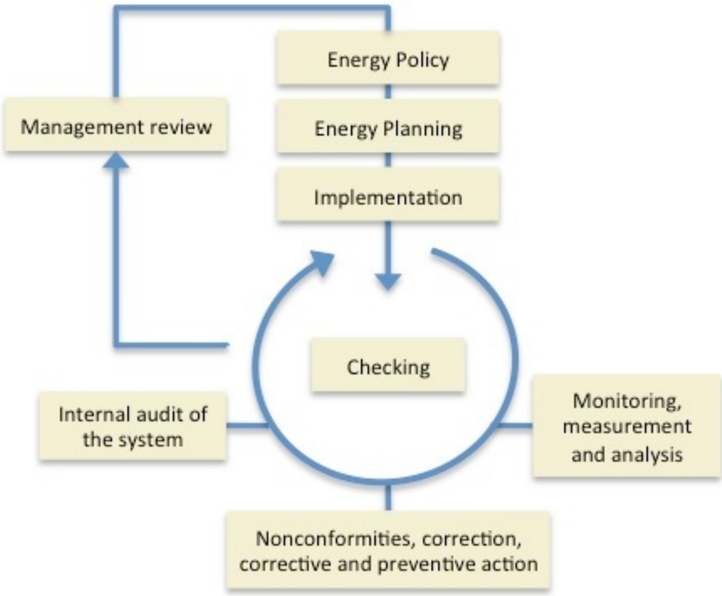
A management system is a set of activities and procedures that an organisation needs to follow in order to meet its objectives (ISO 2013). With regard to improving energy efficiency, worldwide several management systems are described that aim to help organisations to adapt solid energy management. Two energy management systems (EMS) are analysed: the "ISO-NEN-EN 50001 Energy Management System" (Nederlands Normalisatie-instituut (NEN) 2011) and the "Carbon Trust (CT) Energy Management Roadmap" (Carbon Trust 2010). Although this paper focuses on the energy performance of the built environment and energy management is a general approach applicable to every energy-consuming element in an organisation, the two EMSs are described with the purpose to be applied to sub themes or departments and can therefore be very useful in this paper. The presence of this system should be envisioned as the required organisational environment to perform solid energy management and thus to make decisions on BMR activities aimed at energy performance. The aim of the elaboration on the EMSs is this paper is to give insight in the organisational requirements, before going into detail on the specific decisions that need to be made.

NEN-EN-ISO-50001

The International Organisation for Standardisation (ISO) developed several management system standards, including an Energy Management System. This directive is a general management system that can be applied to different scales of organisations and different assets such as machines, systems but also to buildings. In the Netherlands, the ISO-standard is translated into the directive NEN-EN-ISO-50001 "Energy Management System", a guiding standard in implementing or examining Energy Management. "This International Standard specifies energy management system (EnMS) requirements, upon which an organization can develop and implement an energy policy, and establish objectives, targets, and action plans which take into account legal requirements and information related to significant energy use" (Nederlands Normalisatie-instituut (NEN) 2011).

The standard is based on the Deming Circle: Plan – Do – Check – Act; this means that an Energy Management system is intended as a continuous improvement framework in everyday organizational practices (Nederlands Normalisatie-instituut (NEN) 2011) as can be seen in Appendix figure 3 and explained below:

3) "Plan: conduct the energy review and establish the baseline, energy performance indicators, objectives, targets and action plans necessary to deliver results that will improve energy performance in accordance with the organization's energy policy (management review, energy policy, energy planning);
4) Do: implement the energy management action plans (implementation);
5) Check: monitor and measure processes and the key characteristics of operations that determine energy performance against the energy policy and objectives, and report the results (checking);
6) Act: take actions to continually improve energy performance and the EnMS (management review)"

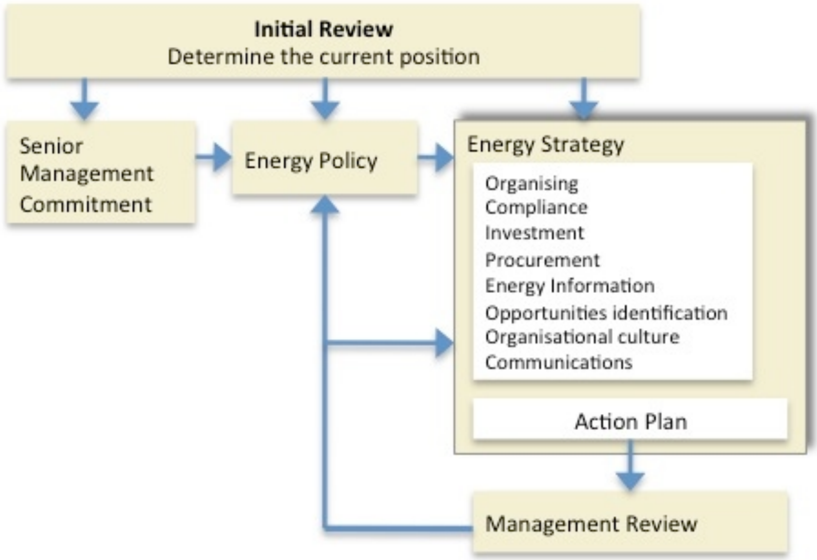


Appendix figure 3 – Energy management system model for the ISO 50001 standard (Nederlands Normalisatie-instituut (NEN) 2011)

This approach describes the process of developing and reviewing a management system and briefly describes what the activities of the management system should entail in the 'energy planning' step. This step comprises an analysis of the energy use, identification of areas of significant energy use and identification of improvement opportunities, resulting in action plans on how to improve the energy performance. These action plans are dependent on the specific area subject to the new management system.

Carbon Trust Roadmap to Energy management

Carbon Trust (CT) an independent organisation from the United Kingdom that is operating worldwide with the aim to tackle climate change, developed several documents (based on former ISO standards) that businesses and public sector organisations can use as a guide to energy management. Their guides provide a hands-on approach to different elements of energy management reaching from monitoring and targeting, to building fabric, to heating, ventilating and air conditioning; this indicates the more in-depth approach for buildings. However, these elements are not part of the roadmap described in this paragraph. CT also offers certification for Energy Management. The roadmap as shown in Appendix figure 4 summarises the different elements of the Energy Management System described by CT. The first step in developing a system is by determining the current position of the organisation. This will function as input for consequently the senior management, the energy policy and energy strategy. The energy strategy consists of eight elements that together should result in an action plan that should be implemented. Consequently, management reviews whether the action plan complies with the policy and possibly reviews the action plan.



Appendix figure 4 – Roadmap of the different elements of Energy Management by Carbon Trust (Carbon Trust 2010)

Both NEN and CT frameworks determine multiple levels that are of importance in developing the system, of which management commitment, energy policy, strategy and consequently the development of an action plan are the core elements. Both frameworks described more less the environment in which decision making on energy efficiency should take place and what type of procedures should be followed or established. A basic principle for is the Deming Plan-Do-Act-Check circle in which reviewing the system and its results and adjusting the core elements. A main principle in this implied by both models is that energy management should be continuously present in an organisation to optimise and retain energy efficiency. Applying this to buildings, consider that a building is constantly subject to change caused by time, use, maintenance, and weather, resulting in a performance change. Single attention to energy efficiency is thus not enough; this might cause the energy efficiency to decrease. Continuous monitoring of the energy efficiency by effective energy management can prevent this. Besides that, both organisations name the importance of a specific action plan that manifests all decisions and ideas on a tactical level; however, how this action plan can be developed is not prescribed. The procedures or starting points mentioned by both EMSs play an important role in the development of the action plan by guiding decision making. For example, setting targets for improving energy efficiency will help decision makers what interventions to choose to achieve these targets. Following are the main characteristics for the desired organisational environment that were deducted from the two frameworks. Note that this can be applicable on an organisational level as well as departments within the organisation.

- There is management commitment for energy management, translated into the appointment of a management representative and responsible employees that receive training and development if necessary.
- This commitment is translated into a clear vision and strategy on energy management that is communicated throughout the organisation or department.
- The scope and boundaries concerning energy use that need to be addressed are determined.
- Objectives and targets including long-term vision are set.
- Key performance indicators including Energy Performance Indicators (EnPI's) are determined.
- There is legal compliance on energy related legislations.
- There is a procurement procedure for energy procurement and energy consuming products.
- There is a financing procedure for energy investments.
- A baseline check or as-is state analysis is performed.
- There is an identification and analysis procedure on improvement areas.
- Improvement opportunities are prioritized.
- A regular energy review is performed.
- The systems and its results are regularly reviewed and procedures are adjusted if necessary.

Appendix figure 5 – Energy Management System characteristics (adapted from NEN 2011; Carbon Trust 2010)

Appendix 3 Key Performance Indicators concerning property and energy performance

Variables of which a specific value determines the desired performance of a business process are called (key) performance indicators (KPI's). Just as organisations aim to achieve their management objectives such as for example earning 5% profit a year, it is important to define objectives and targets when it comes to the performance of property. Examining a building's performance requires the definition of an objectified performance indicator in relation to the functions of the client in the building (Augenbroe & Park 2005). Note that KPI's are variables that a specific organisation labels as important; it might differ for each organisation. KPI's can be of different nature, for example qualitative, quantitative, focusing on a business process itself or on the outcome of this process. Applying all possible improvements concerning energy efficiency with a payback period below five years is process oriented, where the aim to save 10% energy is a situation oriented. Concerning the energy performance and the property performance, performance indicators are for example energy use, sustainability, exploitation cost, user satisfaction and technical condition of a property. These indicators can be measured in various ways. Appendix figure 6 provides an overview on the most important KPI's that are further elaborated below.

Type	KPI	Expressed in
Energy performance	Energy use	kWh electricity, m^3 gas, primary energy use in Joule
	Energy cost	Euro, euro per building, per m^2
	Energy efficiency	Energy Index (Label), RgdBOEI inspection methodology
	Sustainability	Carbon emission, sustainability certificates such as BREEAM, LEED, GPR, GreenCalc,
Property Performance	Technical condition	Depending on the type of inspection methodology, mostly expressed in between 1-6, dependent on number of failures
	Property exploitation cost	Money spend on maintenance
	User satisfaction	Complaints, productivity
	Indoor environmental quality	Air quality, thermal comfort, acoustic quality, visual quality

Appendix figure 6 – Possible performance indicators relating to property and its energy use (develop by author, based on Agentschap NL, 2013; Maassen, 2013)

Because currently in the Netherlands the most specific regulation on existing property relating to energy efficiency is the Energy Index (EI), the EI it is often used to express the energy performance of the building. However, the EI-calculation does not take energy use by business-specific equipment or end-user behaviour into account what often results in the hypothetic amount of energy used in a building largely differing from the real use of energy. The same counts for other sustainability ratings, where a highly sustainable rating does not always correlate with a highly energy efficiency building (Hertzsch et al. 2012). The Energy index is often used as a target when it comes to improving energy efficiency, resulting in the process driven to improve the label instead of reducing energy consumption.

The real amount of energy use can be expressed in units, i.e. kilowatt-hour (kWh) for electricity and cubic meter (m3) for gas and consequently in use per m^2 or time dimension (e.g. year). Besides that, energy use is translated to primary energy use in Joule (i.e. the amount of energy necessary to generate energy at the source). Depending on the price of energy, that is dependent on the type of contract the energy has with the energy supplier and the use of renewable energy, the energy use defines the energy cost. The use of primary energy can be converted to carbon emission (CO2) that defines the climate impact of the energy use. One unit of kilowatt-hour or cubic meter of gas causes an average carbon emission of consecutively 0.597 kilogram and 1.79772 kilogram (SenterNovem 2013b). Large organisations often report their environmental impact expressed as carbon footprint by calculating the total emission caused by the total energy used within the company.

More integral and complex tools used to express energy efficiency go accompanied by a quality mark and are certificates such as BREEAM and LEED that measure the level of sustainability within property or projects, also for buildings that are in-use. Besides this, GPR-building (GPR-gebouw) is a tool to calculate the sustainability that is expressed in marks on themes such as energy, comfort, environment and user quality and GreenCalc is a tool to measure energy including use of water and materials. As mentioned before, a high sustainable rating does not always correlate with a highly energy efficient building because these ratings consider multiple elements besides energy efficiency (Hertzsch et al. 2012); energy sources, water usage and waste generation are typically other elements considered in sustainability ratings. Therefore, these certificates are not useful in frequent measurement of the property performance with the aim to indicate efficiency improvements, but should rather be seen as a way to express the realised improvements as part from the total organisations or buildings sustainable performance.

Besides the energy use related performance, managing property is often driven by the KPI's indoor environmental quality or technical quality of the building elements and systems (Herik et al. 2013). Especially the balance between indoor environmental quality and the technical quality is of importance in traditional maintenance, repair and operations. Partially depending on the value attached by an organisation to the above-mentioned KPI's, the currently most important KPI when managing property is cost. Apart from trends that are now seen, organisations have limited capital resources to achieve their profitability aim. However, as stated earlier, due to property serving strategic aims of the organisation but also because especially in current economy all activities focus on core business, financial resources for property are limited.

Following are two examples of KPI lists mentioned in literature. Note the difference between KPI's indicating a property performance, and KPI's indicating property management performance. In the light of Energy Service Contracting, Agentschap NL distinguishes five areas in which the performance of BMR can be placed and managed: user satisfaction, sustainability, cost-quality relation, indoor environmental quality, and innovation (Herik et al. 2013). Augenbroe made a division between the aspects Energy, Lighting, Thermal Comfort, and Maintenance. The first three determine the performance of the actual building, while the Maintenance aspects determine the performance of how the building performance is achieved (Augenbroe & Park 2005).

Resultaatgebied	KPI	Voorbeeldwaarde	Meting
A. Klanttevredenheid	Overall	= 3,5 (schaal 1 t/m 5)	1. Enquête 1 2. Klachtenregistratie
	Klimaat	= 3,5 (schaal 1 t/m 5)	Enquête 1
	Dienstverlening	= 3,5 (schaal 1 t/m 5)	Enquête 2
B. Duurzaam Beheer	Elektriciteit / m2	= 90 kWh / m²	Meting per maand
	Gas / m2	= 14 m³ / m²	Meting per maand
	Stadswarmte / m2	= 0,25 GJ / m²	Meting per maand
C. Optimale kosten / kwaliteit	Onderhoudskosten / m2	= €10 / m²	Meting per maand
	Energiekosten / m2	= €15 / m²	Meting per maand
	Status installaties	Afspraak over niveau bij technische check	• NEN 2767 • Alternatieve status meting
	Storingen	= x per maand	# Storingen
	Responstijd	# uur voor type 1 # dagen voor type 2	Respons tijd en hersteltijd via GBS
	Veiligheid / Wettelijk / Arbo	Verplichte checks / inspecties / eisen (ja/nee)	Meting per 6 maanden
D. Binnenklimaat	Temperatuur	20°C	Thermometer
	CO_2-concentratie	650 ppm	CO_2-concentratie
	Licht	300 lux	Luxmeter
	Geluidsniveau	< 80 dB	Geluidsmeter
E. Innovatie	Vernieuwing	Ingevoerde verbetervoorstellen	# ingevoerde verbetervoorstellen
	Revisie gegevens	Revisiegegevens up to date	Steekproef revisie gegevens per kwartaal

Appendix figure 7 – KPI's in Dutch according to (Herik et al. 2013)

Aspect	Function	PI	Meaning	Calculated by:
Energy	Energy	1–7	heating, cooling, humidifying, lighting, pumps, fans, hot water (MJ)	NEN (1999)
Lighting	Energy efficacy	1	electric lighting energy consumption (kW h/m^2·year)	NEN (1999)
		2	luminous efficacy of luminaires in LER (lumens/watt)	National Electrical Manufacturers Association (2001)
		3	daylighting autonomy: per cent of hours without requiring an electric lighting	IESNA (2001)
	Task lighting	4	ratio of task illuminance as installed and as required	IESNA (2001)
	View to outside	5	outward visibility (view to outside): percentage of occupants who can see the outside from their workplaces	n/a
	Visual comfort	6	daylighting glare avoidance: percentage of office hours in discomfort range (Daylighting Glare Index ≥24, just uncomfortable)	Chauvel *et al.* (1982)
		7	shading devices for glare avoidance and energy saving (under development)	n/a
Thermal comfort	Air diffusion	1	occupants in comfort (%)	ASHRAE (2001)
	Asymmetrical thermal radiation due to hot/cold glazing	2	hourly average Predicted Percentage Dissatisfied (PPD) during office hours over one year	ASHRAE (1992, 2001)
		3	hours (%) where the PPD is in the comfort range (10%)	
		4	average of PPD, where PPD is in the comfort range	
	Cold draft caused by glazing	5	hourly average PD during office hours over one year	Fanger and Christensen (1986), Heiselberg (1994)
		6	hours (%) where the PD is in the comfort range (10%)	
		7	average of PD, where PD is in the comfort range	
	Occupants' variation	8	average PPD of workers in different activities and clothing levels	ASHRAE (2001)
	Zoning	9	airflow rate variation in different rooms within a single thermostat zone	Friedman (2004)
	System's capacity and response time	10	minutes required to increase the zone temperature by 1°C under the peak heating load	n/a
		11	minutes required to decrease the zone temperature by 1°C under the peak cooling load	
Maintenance	Efficiency	1	Building Performance Indicator (BPI), scaled from 0 to 100	Shohet *et al.* (2003)
		2	Maintenance Efficiency Indicator (MEI)	
	Business and organization	3	Manpower Sources Diagram (MSD): ratio of in-house and outsourcing expenditures	
		4	Managerial Span of Control (MSC): ratio of a manager and subordinated personnel	
		5	Business availability (%):available floor area over an entire floor area over one year	Chan *et al.* (2001)
		6	Manpower Utilization Index (MUI) (%): ratio of man-hours spent on maintenance and total available man-hours	
		7	Preventive Maintenance Ratio (PMR) (%): ratio of man-hours spent on preventive maintenance and total maintenance (preventive plus corrective)	Barber and Hilberg (1995)
	Failure frequency and timeliness	8	Urgent Repair Request Indicator (URI) and General Repair Request Indicator (GRI): occurrence/10 000 m^2	Chan *et al.* (2001)
		9	average time to repair (ATTR): unit repairing time (h)	
	Policy	10	maintenance productivity: state/$ (under development)	Augenbroe and Park (2002)

Appendix figure 8 – KPI's according to (Augenbroe & Park 2005)

Appendix 4 Regulatory compliance concerning building and energy performance

Every organisation should be compliant with (legal) regulations subject to their business, also regarding their properties and associated processes. Periodically gaining insight into obligations applicable to the specific sector or type of property is essential in securing an organisations regulatory compliance. This appendix provides a general overview of property specific requirements within the field of energy and property performance.

The Multi Year Agreement Energy Efficiency (MJA) and the Multi Year agreement Energy Trading Schedule (MEE) are national covenants that focus on organisations to improve the energy efficiency of their organisations (i.e. buildings and other processes). The MJA3 (Multiyear Agreement Energy Efficiency) is a covenant in which public and private organisations voluntarily can participate. These organisations agreed on improving energy efficiency with 2% each year and are obligated to implement an Energy Efficiency Plan that aims to reach this objective. The following sectors are part of MJA: higher education, hospitals, financial institutions and supermarkets (Agentschap NL 2011a). The MEE for Emission Trading Scheme-companies on EU level is a covenant in which high-energy consuming companies are obligated to participate and focuses on energy saving and reducing the emission of greenhouse gases with 21% by 2020. The following industries are subject to the MEE: breweries, chemical industry, glass industry, metallurgical industry, paper industry and refineries (Agentschap NL 2011a). Being part of one of these covenants obligates or voluntarily commits organisations to improving the energy efficiency. In the Roadmap Energy Conservation Built Environment is evaluated that these local governmental bodies initiatives are successful when it comes to energy saving (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties 2011), however, note that these savings are on much more than savings caused by improved building energy efficiency.

As described in the introduction of this paper, there are two main requirements concerning the specific energy performance of existing non-domestic buildings in the Netherlands. These requirements are based on the EU Energy Performance of Buildings Directive (EPBD). Firstly, all the companies who are expected to be compliant to the Environmental Permit (i.e. Milieuwet) and use more than 50,000 kWh electricity or more than 25,000m^3 are obligated to implement all energy efficiency improvements with a payback time less than five years. Recent research shows that a part of the compliant organisations are not aware of this regulation and only 27% is (almost) compliant with the rule (Bakker et al. 2012). Secondly, since 2008, property owners are obligated to show the Energy Label from a building when selling, renting out or largely renovating a property. This Label (A to G where A is the best) results from the Energy Index that expresses how energy efficient a building is by comparing the hypothetic amount of energy that a building uses, based on envelope characteristics, the installations and the standardised use of energy for heating, cooling, ventilating and lighting, with a standardised level of energy use for that type of building. For buildings with public functions over 1000 m^2, since 2009 the energy label should be publically visible. For new buildings, there is a maximum allowed index level that is called the EPC (Energy Performance Coefficient). This EPC is recently lowered and is also brought into effect for refurbishment of existing buildings where more than 25% of the façade is renovated. Unfortunately, this obligation causes organisations to limit refurbishment to 25% or less instead of facing the opportunity to increase energy efficiency.

Concerning the safety and comfort of building users, which are often employees, there is a labour standard that determines the required working conditions (Arbeidsomstandighedenwet). It defines the minimum safety and health requirements of an environment. Besides these requirements regarding energy use, safety and comfort, the requirements on technology are described in the Dutch Building Code. For example technical characteristics such as the minimum required return of a technical system is defined in this code and should be comply with in every realisation or refurbishment project. Everyone concerned with decision making on technical aspects of a building should be aware of this, and changes in, legislative document. The code exists of rules concerning utility, safety, health, environment and energy efficiency. Appendix figure 9 summarises the above legislator explanation.

Sector / Obligations	Municipa-lities	Education	Culture	Health care	Financial institutions
Apply all energy improve interventions with payback < 5 years	For all organisations that use more than 50,000 kWh or 25,000 m^3 gas				
Energy Label	For all buildings that are sold, rented out or with public function and larger than 1000 m^2				
Comply to EPC demand	For existing buildings applicable in case of refurbishment concerning >25% of the building size				
Comply with covenant objectives on sustainability		MJA		MJA	MJA
Comply with working conditions law (Arbo)	For all employing organisations				
Comply with Building Code	For all buildings				

Appendix figure 9 – Overview of legal obligations in the Netherlands concerning energy or building performance per sector

Appendix 5 Vensim formulas

- (01) Annual additional maintenance expenditures=
  NEW Annual maintenance expenditures-BASE Annual maintenance expenditures
  Units: euro/year
- (02) Annual energy expenditure savings=
  NEW Annual energy expenditures-BASE Annual energy expenditures
  Units: euro/year
- (03) BASE Annual absolute energy savings=
  ((Initial use of electricity-BASE Annual use of electricity)*Mega Joule value electricity)+((Initial use of gas-BASE Annual use of gas)*Mega Joule value gas)
  Units: Megajoule/year
- (04) BASE Annual energy and maintenance expenditures=
  BASE Annual energy expenditures+BASE Annual maintenance expenditures
  Units: euro/year
- (05) BASE Annual energy expenditures=
  (-BASE Annual use of electricity*Electricity price)+(-BASE Annual use of gas*Gas price)
  Units: euro/year
- (06) BASE Annual maintenance expenditures=
  ((-Non energy efficiency related annual maintenance expenditures(Time))+(-BASE Energy efficiency related annual maintenance expenditures(Time)))*Maintenance price effect
  Units: euro/year
- (07) BASE Annual use of electricity=
  Initial use of electricity+BASE Change in use of electricity
  Units: Kilowatt hour/year
- (08) BASE Annual use of gas=
  Initial use of gas+BASE Change in use of gas
  Units: cubic meter of gas/year
- (09) BASE Carbon footprint of property=
  BASE Annual use of electricity*Carbon emission for electricity+Carbon emission for gas*BASE Annual use of gas
  Units: kilogram CO2/year
- (10) BASE Change in use of electricity=0
  Units: Dmnl
- (11)BASE Change in use of gas=0
  Units: Dmnl
- (12) BASE Cumulative absolute energy savings=
  INTEG (BASE Annual absolute energy savings,0)
  Units: Megajoule
- (13) BASE Cumulative amount of electricity used=
  INTEG (BASE Annual use of electricity,0)
  Units: Kilowatt hour
- (14) BASE Cumulative amount of gas used=
  INTEG (BASE Annual use of gas,0)
  Units: cubic meter of gas
- (15) BASE Cumulative energy and maintenance expenditures=
  INTEG (BASE Annual energy and maintenance expenditures,   0)
  Units: euro

- (16) BASE Cumulative energy expenditures=
  INTEG (BASE Annual energy expenditures,0)
  Units: euro
- (17) BASE Cumulative maintenance expenditures=
  INTEG (BASE Annual maintenance expenditures,0)
  Units: euro
- (18) BASE Energy efficiency related annual maintenance expenditures
  (GET XLS LOOKUPS('?Stadhuis werkboek' , 'uitvoer' , '2' , 'B11'))
  Units: Dmnl
- (19) BASE Net Present Value of energy and maintenane expenditures=
  NPVE(BASE Annual energy and maintenance expenditures, Discount rate, 0,1)
  Units: euro
- (20) BASE Relative energy savings=
  (BASE Annual absolute energy savings/(Initial use of electricity*Mega Joule value electricity+Mega Joule value gas*Initial use of gas))*100
  Units: Percentage
- (21) Carbon emission for electricity=0.59686
  Units: kilogram CO2/Kilowatt hour
- (22) Carbon emission for gas=1.79772
  Units: kilogram CO2/cubic meter of gas
- (23)Discount rate=0.05
  Units: Fraction
  (24) Electricity price=
  Electricity price effect*Initial electricity price
  Units: euro/Kilowatt hour
- (25) Electricity price effect=
  power((1+Electricity price rate+Inflation rate),(Time))
  Units: Dmnl
- (26) Electricity price rate=0.01
  Units: fraction
- (27) FINAL TIME = 20
  Units: year
  The final time for the simulation.
- (28) Gas price=
  Initial gas price*Gas price effect
  Units: euro/cubic meter of gas
- (29) Gas price effect=
  power((1+Gas price rate+Inflation rate),(Time))
  Units: Dmnl
- (30) Gas price rate=0.04
  Units: fraction
- (31) Inflation rate=0.02
  Units: fraction
- (32) Initial electricity price=0.11
  Units: euro/Kilowatt hour
- (33) Initial gas price=0.5
  Units: euro/cubic meter of gas

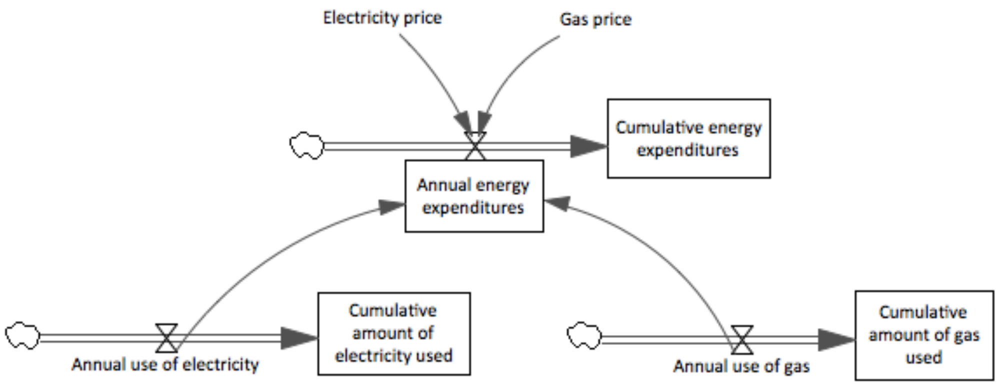
- (34) INITIAL TIME = 0
Units: year
The initial time for the simulation.
- (35) Initial use of electricity=1.9858e+06
Units: Kilowatt hour/year
- (36) Initial use of gas=251570
Units: cubic meter of gas/year
- (37) Maintenance price effect=
power((1+Maintenance price rate+Inflation rate),(Time))
Units: Dmnl
- (38) Maintenance price rate=0.005
Units: fraction
- (39) Mega Joule value electricity==3.6
Units: Megajoule/Kilowatt hour
- (40) Mega Joule value gas==35.2
Units: Kilojoule/cubic meter of gas
- (41) Net present value of additional maintenance expenditures=
NPVE(Annual additional maintenance expenditures,Discount rate,0,1)
Units: euro
- (42) Net present value of energy efficiency interventions=
Net present value of energy expenditure savings+Net present value of additional maintenance expenditures
Units: euro
- (43) Net present value of energy expenditure savings=
NPVE(Annual energy expenditure savings,Discount rate,0,1)
Units: euro
- (44) NEW Annual absolute energy savings=
((Initial use of electricity-NEW Annual use of electricity)*Mega Joule value electricity)+((Initial use of gas-NEW Annual use of gas)*Mega Joule value gas)
Units: Megajoule/year
- (45) NEW Annual energy and maintenance expenditures=
NEW Annual energy expenditures+NEW Annual maintenance expenditures
Units: euro/year
- (46) NEW Annual energy expenditures=
(-NEW Annual use of electricity*Electricity price)+(-NEW Annual use of gas*Gas price)
Units: euro/year
- (47) NEW Annual maintenance expenditures=
((-NEW Energy efficiency related annual maintenance expenditures(Time))+(-Non energy efficiency related annual maintenance expenditures(Time)))*Maintenance price effect
Units: euro/year
- (48) NEW Annual use of electricity=
Initial use of electricity-(NEW Change in use of electricity(Time)*Uncertainty on change in use of electricity)
Units: Kilowatt hour/year
- (49) NEW Annual use of gas=
Initial use of gas-(NEW Change in use of gas(Time)*Uncertainty on change in use of gas)
Units: cubic meter of gas/year

- (50) NEW Carbon footprint of property=
  (NEW Annual use of electricity*Carbon emission for electricity+Carbon emission for gas*NEW Annual use of gas)
  Units: kilogram CO2/year
- (51) NEW Change in use of electricity
  (GET XLS LOOKUPS('?Stadhuis werkboek', 'uitvoer' , '2' , 'B26'))
  Units: Dmnl
- (52) NEW Change in use of gas
  (GET XLS LOOKUPS('?Stadhuis werkboek', 'uitvoer' , '2' , 'B27'))
  Units: Dmnl
- (53) NEW Cumulative absolute energy savings=
  INTEG (NEW Annual absolute energy savings,0)
  Units: Megajoule
- (54) NEW Cumulative amount of electricity used=
  INTEG (NEW Annual use of electricity,0)
  Units: Kilowatt hour
- (55) NEW Cumulative amount of gas used=
  INTEG (NEW Annual use of gas,0)
  Units: cubic meter of gas
- (56) NEW Cumulative energy and maintenance expenditures=
  INTEG (NEW Annual energy and maintenance expenditures,0)
  Units: euro
- (57) NEW Cumulative energy expenditures=
  INTEG (NEW Annual energy expenditures,0)
  Units: euro
- (58) NEW Cumulative maintenance expenditures=
  INTEG (NEW Annual maintenance expenditures,0)
  Units: euro
- (59) NEW Energy efficiency related annual maintenance expenditures
  (GET XLS LOOKUPS('?Stadhuis werkboek' , 'uitvoer' , '2' , 'B25'))
  Units: Dmnl
- (60) NEW Net Present Value of energy and maintenance expenditures=
  NPVE(NEW Annual energy and maintenance expenditures, Discount rate, 0,1)
  Units: euro
- (61) NEW Relative energy savings=
  (NEW Annual absolute energy savings/(Initial use of electricity*Mega Joule value electricity+Mega Joule value gas*Initial use of gas))*100
  Units: Percentage
- (62) Non energy efficiency related annual maintenance expenditures
  (GET XLS LOOKUPS('?Stadhuis werkboek','uitvoer','2','B6'))
  Units: Dmnl
- (63) Uncertainty on change in use of electricity=1
  Units: Dmnl
- (64) Uncertainty on change in use of gas=1
  Units: Dmnl

Appendix 6 Development of the System Dynamics model

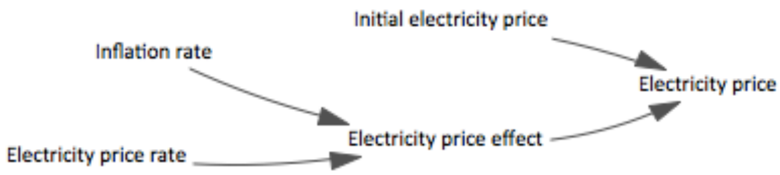
Maintenance and energy expenditures

The two basic parts of the model are the maintenance and energy expenditures. The annual energy expenditures are the sum of the annual use of electricity multiplied by the electricity price and the annual use of gas multiplied by the gas price, shown in Appendix figure 10. For all three flows, the cumulative (i.e. stock) of the annual use and expenditures is calculated by calculating the mathematical integral of the inflow.

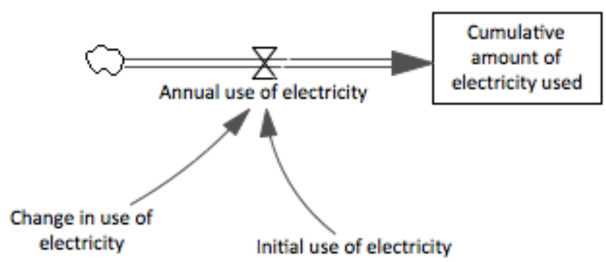


Appendix figure 10 – Annual energy expenditures

The electricity and gas price are both developed by multiplying the initial price by a price effect that is caused by inflation and a price rate. The example for the electricity price is shown in Appendix figure 11. The annual use of electricity or gas is determined by taking the sum of the initial use of electricity and the change in use of electricity. The change in use of electricity is imported together with the maintenance expenditures. Note that this change is determined by calculation or estimation in the decision making process.

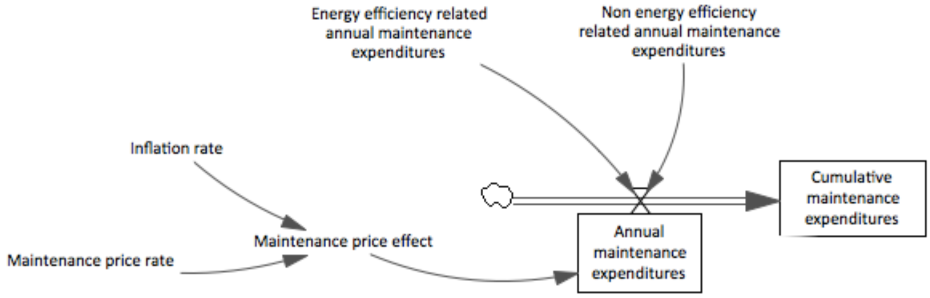


Appendix figure 11 – Electricity price



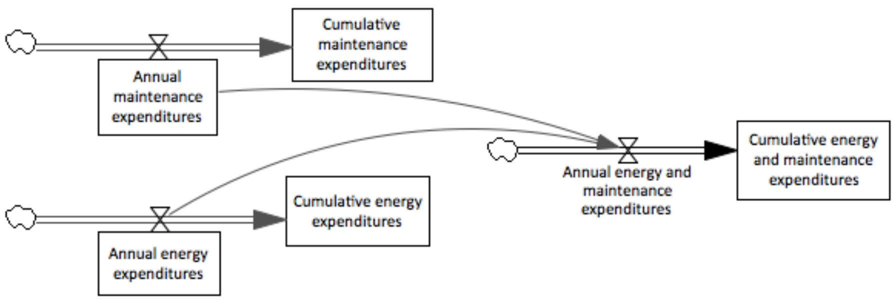
Appendix figure 12 – Annual use of electricity

The annual maintenance expenditures are determined by mainly two variables. 1) the prognosed maintenance cost, split into energy efficiency related and non energy efficiency related expenditures. Both variables are a lookup function that import cash flow data from excel (or indirectly using other software). The other variable is 2) a maintenance price effect, representing inflation and a percentage change in maintenance price.



Appendix figure 13 – Annual maintenance expenditures

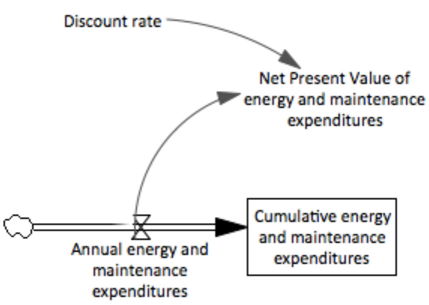
Consequently, the annual maintenance and energy expenditures come together in another flow in which the total cost are calculated.



Appendix figure 14 – Annual energy and maintenance expenditures

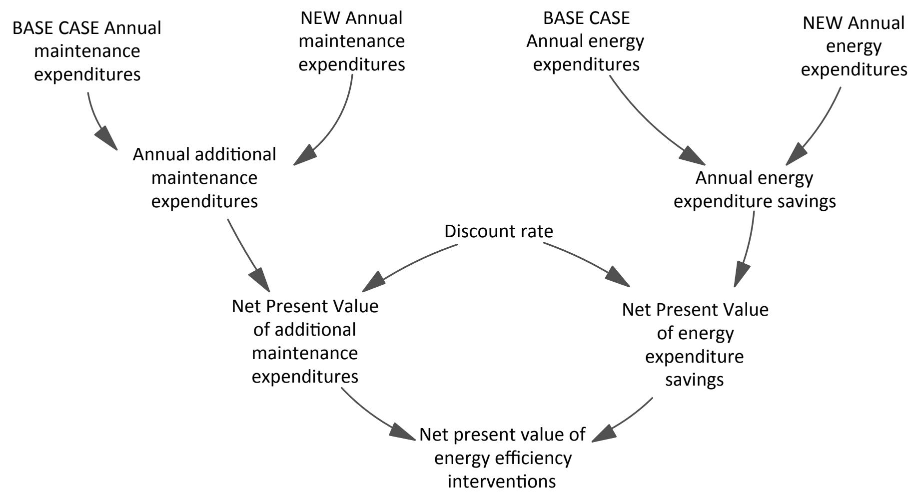
Net present values

Now the basics are modelled and can be applied to both approaches, it is of importance to turn this information into useful information for organisations so the model will provide useful insight. The NPV of the energy expenditures, the NPV of the maintenance expenditures and the NPV of all energy and maintenance expenditures are calculated and represent the sum of the discounted cash flows for this specific element.



Appendix figure 15 – Net Present Value of energy and maintenance expenditures

The Net Present Value of the combination of energy efficiency interventions is calculated by adding the additional annual maintenance expenditures (i.e. the energy efficiency related maintenance expenditures for the base scenario – new scenario) as negative cash flow to the energy savings (i.e. base annual energy expenditures – new annual energy expenditures) and discounting these cash flows for each year back to present. Appendix figure 16 visualises the interrelationships of the aforementioned variables.



Appendix figure 16 – Net Present Value of energy efficiency interventions

Additional output

The annual use of electricity and gas is used to calculate the annual carbon emission for the property. The carbon emission for electricity is 0.59686 kg/kWh and for gas 1.79772 kg/m^3 (SenterNovem 2013b). Attention should be paid to the accuracy of the value of the carbon emission for electricity due to its dependency of the type of generation. The absolute annual energy savings are calculated by comparing the initial energy use of electricity and gas with the annual use of energy, translated into Mega joule. These absolute savings are used to calculate the relative (percentage) of savings, based on initial and annual use of absolute energy (i.e. Mega Joule).

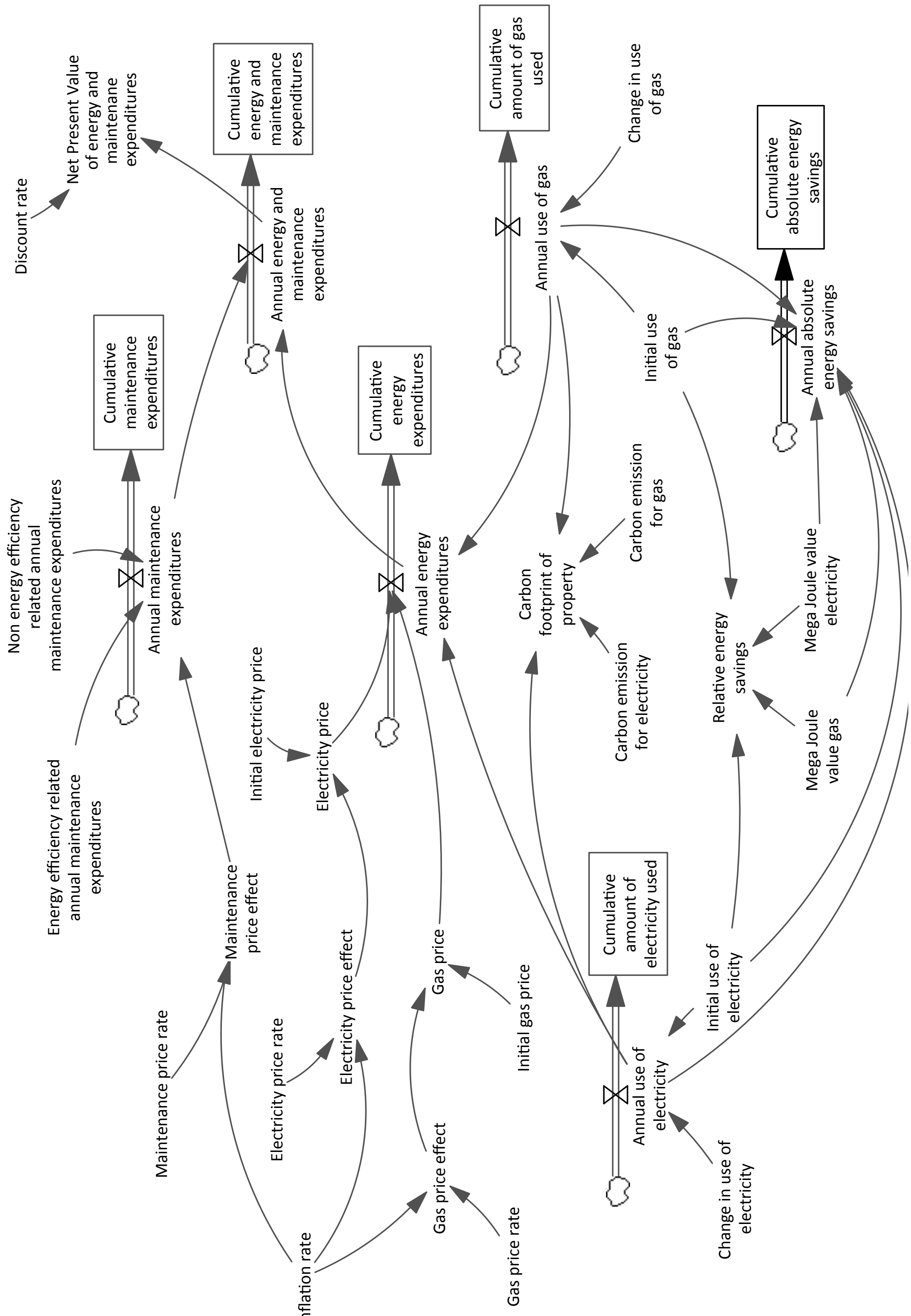
Mathematical expression of a stock

The mathematic expression of the equation to determine the stock value is the following, where stock(t_0) represents the initial stock level:

$$Stock(t) = \int_{t_0}^{t} [inflow(s) - outflow(s)]ds + stock(t_0)$$

In the calculation model developed for the assessment tool, no outflows or initial stocks are modeled. This strongly simplifies the expression.

The above explanation results in the basic calculation model as can be seen in Appendix figure 17. The calculation models shown on page 35 and 38 are based on this basic calculation model.



Appendix figure 17 – Basic calculation model

Appendix 7 Energy saving calculations used in case study

Two types of calculations were performed to estimate the energy savings for the identified improvement opportunities. The first calculations determines the electricity savings, the second the gas savings. The electricity savings occur from a direct lower demand in energy use. The gas savings occur from a difference in heat loss due to a change in the thermal resistance of elements. The estimated savings accruing from the placement of a heat and steam recovery element in the Air Handling Unit were adopted from a calculation made by Royal HaskoningDHV (i.e. 77,116 kWh and 5,000 m^3).

Electricity savings

The electricity savings were calculated by multiplying (the difference in) wattage with the operating hours. Basic assumption is that the service systems are in operation on average 10 hours a day, 5 days a week, 52 weeks a year. Concerning the emergency lighting, the operating hours are 24/7/365. The estimated change in operating hours is based on expert input. The savings are calculated by multiplying wattage with the operating hours.

Element	(delta) Wattage	Difference in operating hours per year	Annual savings in kWh
Speed controlled fans large AHU	92 kW (55 + 37 kWh)	520 (2 hours a day)	47,840
Speed controlled fans small AHU's (6 pcs)	28.5 kW (4x4 + 11 + 1.5 kWh)	260 (1 hour a day)	7,410
Redundancy steam machines (6 pcs)	11.4 kW (6x1.9 kW)	300 (when outside relative humidity <40%)	3,420
Speed controlled pumps (8 pcs)	Estimation: 8 kW (8x1kW)	1040 (4 hours a day)	9,880
Emergency lighting (160 pcs)	Δwattage= 0.64 kW (160x0.004 kW)	24x365	5,606

Appendix figure 18 – Annual savings in use of electricity

Delta heat transmission los

As a principle to calculating the difference in heat transmission loss and thus the gas use savings, the equation to calculate heat transmission los as stated in ISSO 75.3 was used to develop a formula that can be applied in this research.

$$H_{tr} = \sum_{k} (a_k \times A_k \times (U_k + U_{kb}))$$

$$\Delta Q_{tr;i} = H_{tr} \times (T_{in} + T_{e;i}) \times t$$

$\Delta Q_{tr;i}$ = heat transmission los in month i	[MJ]
i = month	[-]
H_{tr} = heat transmission los	[W/K]
T_{in} = temperature inside	[°C]
$T_{e;i}$ = average outside (external) temperature in month i	[°C]
t = time in month	[Ms]
a_k = correction for type of object	[-]
A_k = area subject to heat transmission los	[m^2]
U_k = thermal resistance of area subject to transmission los	[W/m^{2}K)
U_{kb} = correction for thermal bridges	[W/m^{2}K)

Because for this research, the yearly energy savings need to be calculated, the time factor of one month should be eliminated or translated to the heat transmission in one year. This means that the heating degree-days (HDD) for each month should be turned into heating degree-days for a year. HDD provides a simple metric for quantifying the amount of heating what buildings in a particular location need over a certain period. For offices, the desired temperature is 19 °C (page 22 of 75.3 ISSO Kennisinstituut voor de Installatiesector 2011). Calculating the heating degree-days can be done by calculating one-degree day for every delta degree present on a day over a period of time. For offices, the assumed degree-days are (based on Matrix Nijmegen) 3000.

Function	HDD
Sports facility	1200
Offices	3000
Community Centre	2500
Workplace	1800
Education	2000

Appendix figure 19 – Heating degree days per year (Matrix Nijmegen RHDHV, 2013)

7) Assuming that the correction for thermal bridges (i.e. correcting the thermal loss caused by thermal bridges), and the correction for type of object (i.e. reduction of thermal loss due to object area bordering area with other temperature than external temperature) will not change when an intervention is implemented, these two factors are not of interest in the calculation.
8) The los of transmission per joule is required to know assuming that the energy is produced by a boiling system, therefore, the transmission loss is multiplied by 24 (i.e. hours in a day) and 3600 (i.e. seconds in an hour).

This turns the formula into:

$$\Delta Q_{tr;y} = A_k \times (U_{new} - U_{old}) \times HDD_{l;y} \times 24 \times 3600$$

$\Delta Q_{tr;y}$ = difference in heat transmission los in a year	[J/s]
A_k = area subject to heat transmission los	[m^2]
$\Delta U = U_{new} - U_{old}$ = difference between new and old thermal resistance	[W/m^{2}K)
$HDD_{l;y}$ = heating degree days per year for building location	[Kh/1]

Depending on the type of heating system, the actual energy saving can be calculated. This is done by dividing the heat transmission los in a year by the caloric value of gas that is corrected by the yield of the heating system.

$$\Delta E = \Delta Q_{tr;y} \div (H_{gas} \div \eta_{hs})$$

ΔE = difference in use of gas [m³]
H_{gas} = caloric value of gas (35200000) [J/m³]
$\eta_{com;hs}$ = gas combustion yield of heating system [-]

For the case of Nijmegen, the combustion yield of the heating system is, knowing that the current boiling system is Novumax LN 1050 (HR 107) and based on ISSO 75.3 page 45, set at a yield of 0.90. The yield of the entire system (i.e. taking heat loss into account due to low piping insulation etcetera) is considered of negligible value.

Element	Area	ΔR_c	Annual savings in m^3
Roof insulation	2600 m^2	1.5	31,909
Floor insulation	1558 m^2	1	12,747
Glazing HR+++	1639 m^2	1.3	17,433
Window frames	1000 m^2	2	16,364

Appendix figure 20 – Annual savings in use of gas

Appendix 8 City Hall case input, output dataset and sensitivity graphs

Cash flows and energy savings

	non-energy efficiency related exp			BASE CASE ee exp			NEW ee exp			effect on energy use	
year	capex	opex	total exp	capex	opex	total exp	capex	opex	total exp	electricity	gas
0	€ -	€ 52,511	€ 52,511	€ 45,760	€ 72,512	€ 118,272	€ 306,252	€ 74,012	€ 380,264	0	0
1	€ -	€ 110,497	€ 110,497	€ -	€ 20,212	€ 20,212	€ 374,699	€ 21,712	€ 396,411	140,424	46,544
2	€ -	€ 67,170	€ 67,170	€ -	€ 21,084	€ 21,084	€ 640,731	€ 22,759	€ 663,490	140,424	46,544
3	€ 47,847	€ 357,444	€ 405,291	€ 181,337	€ 40,212	€ 221,549	€ 217,604	€ 44,212	€ 261,817	257,313	51,544
4	€ -	€ 39,599	€ 39,599	€ -	€ 54,829	€ 54,829	€ 132,533	€ 52,896	€ 185,429	276,051	51,544
5	€ -	€ 79,861	€ 79,861	€ -	€ 21,379	€ 21,379	€ -	€ 21,379	€ 21,379	276,051	83,453
6	€ -	€ 48,356	€ 48,356	€ 35,416	€ 26,505	€ 61,921	€ -	€ 27,763	€ 27,763	276,051	83,453
7	€ -	€ 128,713	€ 128,713	€ 41,325	€ 75,407	€ 116,731	€ 1,827	€ 75,407	€ 77,234	277,401	83,453
8	€ 19,458	€ 109,812	€ 129,270	€ -	€ 37,219	€ 37,219	€ -	€ 35,286	€ 35,286	277,401	83,453
9	€ 301,049	€ 129,419	€ 430,468	€ 12,894	€ 20,212	€ 33,106	€ -	€ 20,212	€ 20,212	277,401	83,453
10	€ 456,882	€ 51,684	€ 508,566	€ -	€ 25,690	€ 25,690	€ -	€ 26,785	€ 26,785	277,401	83,453
11	€ 63,969	€ 179,117	€ 243,086	€ -	€ 39,296	€ 39,296	€ -	€ 39,296	€ 39,296	280,101	83,453
12	€ -	€ 99,422	€ 99,422	€ 69,699	€ 35,745	€ 105,444	€ 69,699	€ 33,812	€ 103,511	280,101	83,453
13	€ -	€ 56,519	€ 56,519	€ -	€ 20,212	€ 20,212	€ -	€ 20,212	€ 20,212	280,101	83,453
14	€ -	€ 56,799	€ 56,799	€ -	€ 73,986	€ 73,986	€ -	€ 73,986	€ 73,986	280,101	83,453
15	€ -	€ 137,124	€ 137,124	€ -	€ 20,212	€ 20,212	€ -	€ 20,212	€ 20,212	280,101	83,453
16	€ -	€ 48,209	€ 48,209	€ 45,760	€ 151,730	€ 197,490	€ 61,760	€ 151,730	€ 213,490	280,101	83,453
17	€ -	€ 60,197	€ 60,197	€ 1,064,259	€ 21,456	€ 1,085,715	€ 320,151	€ 21,630	€ 341,781	280,101	83,453
18	€ -	€ 193,115	€ 193,115	€ -	€ 59,296	€ 59,296	€ -	€ 63,296	€ 63,296	280,101	83,453
19	€ -	€ 64,034	€ 64,034	€ -	€ 70,667	€ 70,667	€ -	€ 70,667	€ 70,667	280,101	83,453
20	€ -	€ 93,872	€ 93,872	€ -	€ 37,219	€ 37,219	€ -	€ 35,286	€ 35,286	280,101	83,453

Appendix figure 21 – Simulation input for lookup functions (grey boxes): cash flows and energy savings

Statistics to determine economic indicators

	CPI	Buildings	Electricity	Gas
Price level	**2006 = 100**	**2000=100**	**2010=100**	**2010=100**
Year				
2000	87.41	94	68	60.9
2001	91.05	99	67.1	75.7
2002	94.04	108	64.4	68.7
2003	96.03	116	68.6	74.3
2004	97.22	121	66.7	72.4
2005	98.85	120	75.9	90.6
2006	100	122	97.8	113.9
2007	101.61	123	102.2	114
2008	104.14	127	113.8	138
2009	105.38	133	104.3	106.2
2010	106.72	134	100	100
2011	109.22	131	100.5	119.5
2012	111.9	128	100.6	133.4
Price increase	1.88%	2.35%	2.97%	5.85%
Correction for inflation	**1.88%**	**0.46%**	**1.09%**	**3.97%**

Appendix figure 22 – Price rate over the last years (adapted from Statistics Netherlands (CBS) n.d.)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Variable Time	0	1	2	3	4	5	6	7	8	9	10
Annual additional maintenance expenditures	€ (261,992)	€ (385,604)	€ (674,927)	€ (43,364)	€ (144,159)	€ (0)	€ 39,613	€ 46,950	€ 2,354	€ 16,103	€ (1,402)
Annual energy expenditure savings	€ -	€ 40,578	€ 42,536	€ 61,624	€ 66,713	€ 91,041	€ 95,448	€ 100,270	€ 105,160	€ 110,310	€ 115,734
BASE Annual absolute energy savings	0	0	0	0	0	0	0	0	0	0	0
BASE Annual energy and maintenance expenditures	€ (515,007)	€ (492,300)	€ (465,795)	€ (1,063,543)	€ (508,884)	€ (536,101)	€ (567,143)	€ (749,541)	€ (680,043)	€ (1,076,463)	€ (1,202,716)
BASE Annual energy expenditures	€ (344,223)	€ (358,323)	€ (373,073)	€ (388,505)	€ (404,655)	€ (421,558)	€ (439,255)	€ (457,785)	€ (477,193)	€ (497,523)	€ (518,824)
BASE Annual maintenance expenditures	€ (170,784)	€ (133,977)	€ (92,722)	€ (675,038)	€ (104,230)	€ (114,543)	€ (127,888)	€ (291,756)	€ (202,850)	€ (578,940)	€ (683,892)
BASE Annual use of electricity	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800
BASE Annual use of gas	251,570	251,570	251,570	251,570	251,570	251,570	251,570	251,570	251,570	251,570	251,570
BASE Carbon footprint of property	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497
BASE Change in use of electricity	0										
BASE Change in use of gas	0										
BASE Cumulative absolute energy savings	0	0	0	0	0	0	0	0	0	0	0
BASE Cumulative amount of electricity used	0	1,985,800	3,971,600	5,957,400	7,943,200	9,929,000	11,914,800	13,900,600	15,886,400	17,872,200	19,858,000
BASE Cumulative amount of gas used	0	251,570	503,140	754,710	1,006,280	1,257,850	1,509,420	1,760,990	2,012,560	2,264,130	2,515,700
BASE Cumulative energy and maintenance expenditures	€ -	€ (515,007)	€ (1,007,307)	€ (1,473,102)	€ (2,536,645)	€ (3,045,530)	€ (3,581,631)	€ (4,148,774)	€ (4,898,315)	€ (5,578,358)	€ (6,654,821)
BASE Cumulative energy expenditures	€ -	€ (344,223)	€ (702,546)	€ (1,075,619)	€ (1,464,124)	€ (1,868,779)	€ (2,290,337)	€ (2,729,592)	€ (3,187,377)	€ (3,664,570)	€ (4,162,093)
BASE Cumulative maintenance expenditures	€ -	€ (170,784)	€ (304,761)	€ (397,483)	€ (1,072,521)	€ (1,176,751)	€ (1,291,294)	€ (1,419,182)	€ (1,710,938)	€ (1,913,788)	€ (2,492,728)
BASE Net Present Value of energy and maintenane expenditures	€ (490,483)	€ (937,013)	€ (1,339,385)	€ (2,214,364)	€ (2,613,089)	€ (3,013,136)	€ (3,416,194)	€ (3,923,513)	€ (4,361,874)	€ (5,022,729)	€ (5,725,932)
BASE Relative energy savings	0	0	0	0	0	0	0	0	0	0	0
Carbon emission for electricity	0.60										
Carbon emission for gas	1.80										
Discount rate	0.05										
Electricity price	0.11	0.11	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.14	0.15
Electricity price effect	1.00	1.03	1.06	1.09	1.13	1.16	1.19	1.23	1.27	1.30	1.34
Electricity price rate	0.01										
Gas price	0.50	0.53	0.56	0.60	0.63	0.67	0.71	0.75	0.80	0.84	0.90
Gas price effect	1.00	1.06	1.12	1.19	1.26	1.34	1.42	1.50	1.59	1.69	1.79
Gas price rate	0.04										

Appendix figure 23 – Case study simulation base run dataset part I

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Time	11	12	13	14	15	16	17	18	19	20
Annual additional maintenance expenditures	€ -	€ 2,599	€ 0	€ -	€ -	€ (23,752)	€ 1,131,983	€ (6,239)	€ -	€ 3,166
Annual energy expenditure savings	€ 121,859	€ 127,891	€ 134,247	€ 140,944	€ 148,003	€ 155,443	€ 163,286	€ 171,555	€ 180,275	€ 189,471
BASE Annual absolute energy savings	0	0	0	0	0	0	0	0	0	0
BASE Annual energy and maintenance expenditures	€ (911,657)	€ (840,066)	€ (694,848)	€ (799,590)	€ (869,640)	€ (1,034,807)	€ (2,443,395)	€ (1,124,584)	€ (978,947)	€ (1,012,740)
BASE Annual energy expenditures	€ (541,147)	€ (564,544)	€ (589,074)	€ (614,795)	€ (641,770)	€ (670,067)	€ (699,755)	€ (730,909)	€ (763,607)	€ (797,932)
BASE Annual maintenance expenditures	€ (370,511)	€ (275,522)	€ (105,774)	€ (184,796)	€ (227,870)	€ (364,740)	€ (1,743,640)	€ (393,676)	€ (215,340)	€ (214,807)
BASE Annual use of electricity	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800	1,985,800
BASE Annual use of gas	251,570	251,570	251,570	251,570	251,570	251,570	251,570	251,570	251,570	251,570
BASE Carbon footprint of property	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497	1,637,497
BASE Change in use of electricity										
BASE Change in use of gas										
BASE Cumulative absolute energy savings	0	0	0	0	0	0	0	0	0	0
BASE Cumulative amount of electricity used	21,843,800	23,829,600	25,815,400	27,801,200	29,787,000	31,772,800	33,758,600	35,744,400	37,730,200	39,716,000
BASE Cumulative amount of gas used	2,767,270	3,018,840	3,270,410	3,521,980	3,773,550	4,025,120	4,276,690	4,528,260	4,779,830	5,031,400
BASE Cumulative energy and maintenance expenditures	€ (7,857,537)	€ (8,769,194)	€ (9,609,260)	€ (10,304,108)	€ (11,103,698)	€ (11,973,338)	€ (13,008,145)	€ (15,451,540)	€ (16,576,124)	€ (17,555,070)
BASE Cumulative energy expenditures	€ (4,680,917)	€ (5,222,063)	€ (5,786,607)	€ (6,375,681)	€ (6,990,475)	€ (7,632,245)	€ (8,302,312)	€ (9,002,066)	€ (9,732,975)	€ (10,496,582)
BASE Cumulative maintenance expenditures	€ (3,176,621)	€ (3,547,131)	€ (3,822,653)	€ (3,928,427)	€ (4,113,223)	€ (4,341,093)	€ (4,705,833)	€ (6,449,473)	€ (6,843,149)	€ (7,058,489)
BASE Net Present Value of energy and maintenance expenditures	€ (6,233,577)	€ (6,679,082)	€ (7,030,027)	€ (7,414,644)	€ (7,813,036)	€ (8,264,518)	€ (9,279,799)	€ (9,724,835)	€ (10,093,790)	€ (10,457,305)
BASE Relative energy savings	0	0	0	0	0	0	0	0	0	0
Carbon emission for electricity										
Carbon emission for gas										
Discount rate										
Electricity price	0.15	0.16	0.16	0.17	0.17	0.18	0.18	0.19	0.19	0.20
Electricity price effect	1.38	1.43	1.47	1.51	1.56	1.60	1.65	1.70	1.75	1.81
Electricity price rate										
Gas price	0.95	1.01	1.07	1.13	1.20	1.27	1.35	1.43	1.51	1.60
Gas price effect	1.90	2.01	2.13	2.26	2.40	2.54	2.69	2.85	3.03	3.21
Gas price rate										

Appendix figure 24 – Case study simulation base run dataset part II

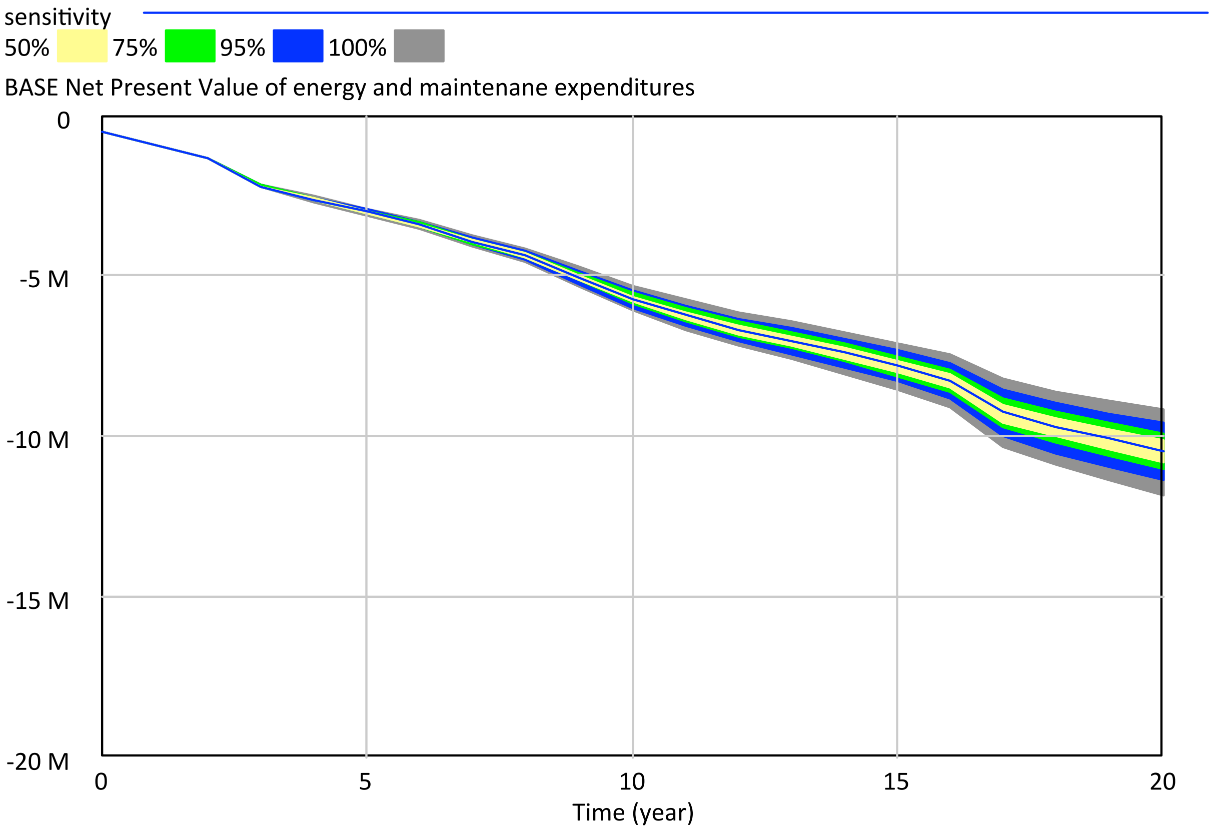
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Time	0	1	2	3	4	5	6	7	8	9	10
Inflation rate	0.02										
Initial electricity price	0.11										
Initial gas price	0.50										
Initial use of electricity	1985800.00										
Initial use of gas	251570.00										
Maintenance price effect	1.00	1.02	1.05	1.08	1.10	1.13	1.16	1.19	1.22	1.25	1.28
Maintenance price rate	0.005										
Mega Joule value electricity	3.60										
Mega Joule value gas	35.20										
Net present value of additional maintenance expenditures	€ (249,516)	€ (599,270)	€ (1,182,298)	€ (1,217,973)	€ (1,330,925)	€ (1,330,925)	€ (1,302,773)	€ (1,270,996)	€ (1,269,478)	€ (1,259,593)	€ (1,260,412)
Net present value of energy efficiency interventions	€ (249,516)	€ (562,464)	€ (1,108,748)	€ (1,093,725)	€ (1,154,406)	€ (1,086,470)	€ (990,484)	€ (890,841)	€ (821,536)	€ (743,929)	€ (677,082)
Net present value of energy expenditure savings	€ -	€ 36,806	€ 73,550	€ 124,248	€ 176,519	€ 244,456	€ 312,289	€ 380,155	€ 447,942	€ 515,663	€ 583,330
NEW Annual absolute energy savings	0	2,143,873	2,143,873	2,740,671	2,808,128	3,931,328	3,931,328	3,936,188	3,936,188	3,936,188	3,936,188
NEW Annual energy and maintenance expenditures	-€776,998	-€837,326	-€1,098,187	-€1,045,283	-€586,330	-€445,060	-€432,083	-€602,322	-€572,529	-€950,050	-€1,088,384
NEW Annual energy expenditures	-€344,223	-€317,745	-€330,537	-€326,881	-€337,941	-€330,517	-€343,807	-€357,516	-€372,033	-€387,213	-€403,090
NEW Annual maintenance expenditures	-€432,775	-€519,581	-€767,650	-€718,401	-€248,389	-€114,543	-€88,276	-€244,806	-€200,496	-€562,837	-€685,294
NEW Annual use of electricity	1,985,800	1,845,376	1,845,376	1,728,487	1,709,749	1,709,749	1,709,749	1,708,399	1,708,399	1,708,399	1,708,399
NEW Annual use of gas	251,570	205,026	205,026	200,026	200,026	168,117	168,117	168,117	168,117	168,117	168,117
NEW Carbon footprint of property	1,637,497	1,470,011	1,470,011	1,391,256	1,380,072	1,322,708	1,322,708	1,321,903	1,321,903	1,321,903	1,321,903
NEW Cumulative absolute energy savings	€ -	€ -	€ 2,143,873	€ 4,287,746	€ 7,028,417	€ 9,836,544	€ 13,767,872	€ 17,699,200	€ 21,635,388	€ 25,571,576	€ 29,507,764
NEW Cumulative amount of electricity used	0	1,985,800	3,831,176	5,676,552	7,405,039	9,114,788	10,824,537	12,534,286	14,242,685	15,951,084	17,659,484
NEW Cumulative amount of gas used	0	251,570	456,596	661,622	861,648	1,061,674	1,229,791	1,397,908	1,566,025	1,734,142	1,902,259
NEW Cumulative energy and maintenance expenditures	€ -	€ (776,998)	€ (1,614,324)	€ (2,712,512)	€ (3,757,794)	€ (4,344,124)	€ (4,789,184)	€ (5,221,267)	€ (5,823,589)	€ (6,396,117)	€ (7,346,168)
NEW Cumulative energy expenditures	€ -	€ (344,223)	€ (661,968)	€ (992,505)	€ (1,319,386)	€ (1,657,328)	€ (1,987,844)	€ (2,331,651)	€ (2,689,167)	€ (3,061,199)	€ (3,448,412)
NEW Cumulative maintenance expenditures	€ -	€ (432,775)	€ (952,357)	€ (1,720,006)	€ (2,438,408)	€ (2,686,796)	€ (2,801,339)	€ (2,889,615)	€ (3,134,422)	€ (3,334,917)	€ (3,897,755)
NEW Net Present Value of energy and maintenance expenditures	€ (739,998)	€ (1,499,478)	€ (2,448,133)	€ (3,308,090)	€ (3,767,495)	€ (4,099,605)	€ (4,406,678)	€ (4,814,353)	€ (5,183,410)	€ (5,766,659)	€ (6,403,014)
NEW Relative energy savings	0.00	13.40	13.40	17.12	17.55	24.56	24.56	24.59	24.59	24.59	24.59
Uncertainty on change in use of electricity	1										
Uncertainty on change in use of gas	1										

Appendix figure 25 – Case study simulation base run dataset part III

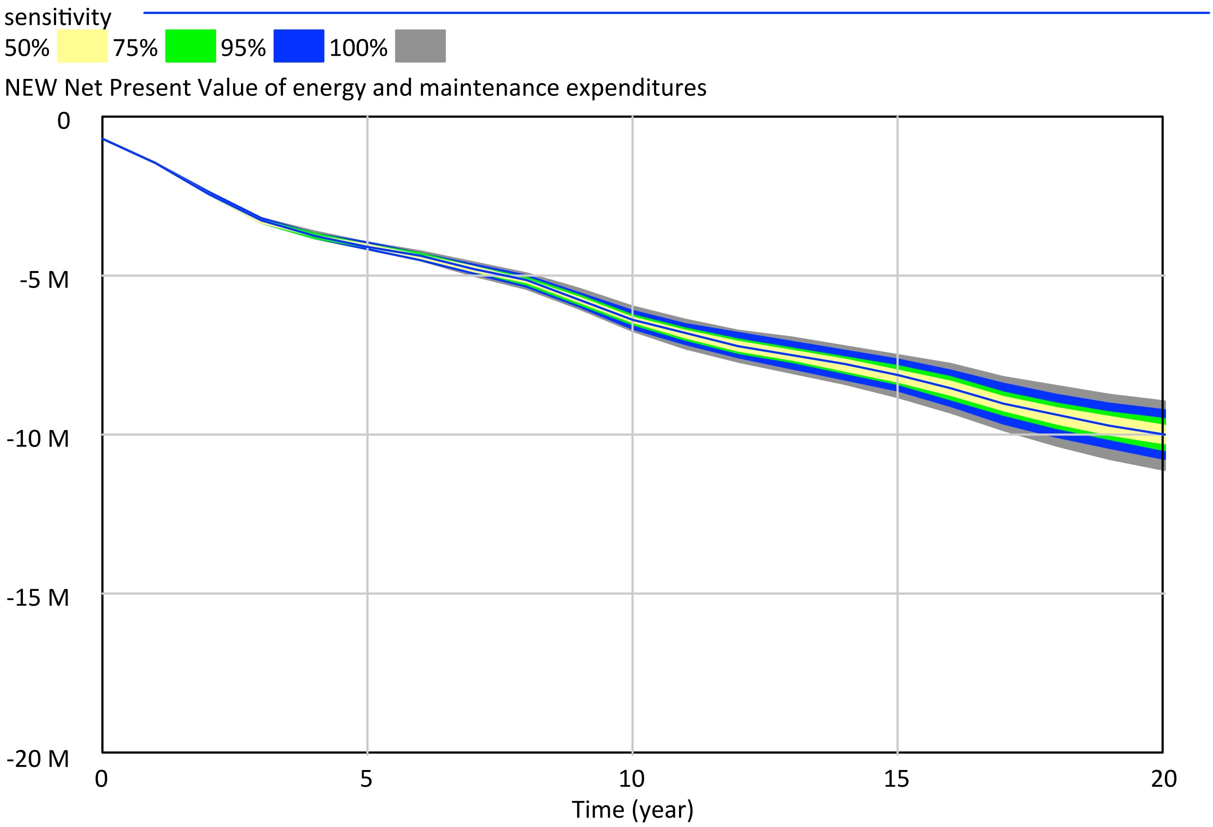
	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Time	11	12	13	14	15	16	17	18	19	20
Inflation rate										
Initial electricity price										
Initial gas price										
Initial use of electricity										
Initial use of gas										
Maintenance price effect	1.31	1.34	1.38	1.41	1.45	1.48	1.52	1.56	1.60	1.64
Maintenance price rate										
Mega Joule value electricity										
Mega Joule value gas										
Net present value of additional maintenance expenditures	€ (1,260,412)	€ (1,259,034)	€ (1,259,034)	€ (1,259,034)	€ (1,259,034)	€ (1,269,397)	€ (799,035)	€ (801,504)	€ (801,504)	€ (800,367)
Net present value of energy efficiency interventions	€ (609,226)	€ (540,025)	€ (472,221)	€ (404,425)	€ (336,623)	€ (279,167)	€ 259,044	€ 324,465	€ 392,409	€ 461,555
Net present value of energy expenditure savings	€ 651,186	€ 719,009	€ 786,813	€ 854,609	€ 922,411	€ 990,230	€ 1,058,079	€ 1,125,969	€ 1,193,913	€ 1,261,922
NEW Annual absolute energy savings	3,945,908	3,945,908	3,945,908	3,945,908	3,945,908	3,945,908	3,945,908	3,945,908	3,945,908	3,945,908
NEW Annual energy and maintenance expenditures	€ (789,798)	€ (709,576)	€ (560,601)	€ (658,646)	€ (721,637)	€ (903,116)	€ (1,148,126)	€ (959,268)	€ (798,672)	€ (820,103)
NEW Annual energy expenditures	€ (419,288)	€ (436,653)	€ (454,827)	€ (473,851)	€ (493,767)	€ (514,624)	€ (536,469)	€ (559,353)	€ (583,332)	€ (608,462)
NEW Annual maintenance expenditures	€ (370,511)	€ (272,923)	€ (105,774)	€ (184,796)	€ (227,870)	€ (388,492)	€ (611,657)	€ (399,914)	€ (215,340)	€ (211,641)
NEW Annual use of electricity	1,705,699	1,705,699	1,705,699	1,705,699	1,705,699	1,705,699	1,705,699	1,705,699	1,705,699	1,705,699
NEW Annual use of gas	168,117	168,117	168,117	168,117	168,117	168,117	168,117	168,117	168,117	168,117
NEW Carbon footprint of property	1,320,291	1,320,291	1,320,291	1,320,291	1,320,291	1,320,291	1,320,291	1,320,291	1,320,291	1,320,291
NEW Cumulative absolute energy savings	€ 33,443,952	€ 37,389,860	€ 41,335,768	€ 45,281,676	€ 49,227,584	€ 53,173,492	€ 57,119,400	€ 61,065,308	€ 65,011,216	€ 68,957,120
NEW Cumulative amount of electricity used	19,367,884	21,073,584	22,779,284	24,484,984	26,190,684	27,896,384	29,602,084	31,307,784	33,013,484	34,719,184
NEW Cumulative amount of gas used	2,070,376	2,238,494	2,406,611	2,574,728	2,742,845	2,910,962	3,079,079	3,247,196	3,415,313	3,583,430
NEW Cumulative energy and maintenance expenditures	€ (8,434,552)	€ (9,224,350)	€ (9,933,926)	€ (10,494,527)	€ (11,153,173)	€ (11,874,810)	€ (12,777,926)	€ (13,926,052)	€ (14,885,320)	€ (15,683,992)
NEW Cumulative energy expenditures	€ (3,851,502)	€ (4,270,790)	€ (4,707,443)	€ (5,162,270)	€ (5,636,120)	€ (6,129,888)	€ (6,644,512)	€ (7,180,981)	€ (7,740,334)	€ (8,323,666)
NEW Cumulative maintenance expenditures	€ (4,583,049)	€ (4,953,560)	€ (5,226,483)	€ (5,332,257)	€ (5,517,052)	€ (5,744,922)	€ (6,133,414)	€ (6,745,071)	€ (7,144,986)	€ (7,360,326)
NEW Net Present Value of energy and maintenance expenditures	€ (6,842,803)	€ (7,219,107)	€ (7,502,248)	€ (7,819,068)	€ (8,149,659)	€ (8,543,685)	€ (9,020,755)	€ (9,400,370)	€ (9,701,381)	€ (9,995,750)
NEW Relative energy savings	24.66	24.66	24.66	24.66	24.66	24.66	24.66	24.66	24.66	24.66
Uncertainty on change in use of electricity										
Uncertainty on change in use of gas										

Appendix figure 26 – Case study simulation base run dataset part IV

Sensitivity run



Appendix figure 27 – Sensitivity graph base scenario



Appendix figure 28 – Sensitivity graph new scenario

Appendix 9 – English summary

EXPLOITING THE ENERGY SAVING POTENTIAL OF NON-RESIDENTIAL CORPORATE PROPERTY - By adopting a new strategy to building maintenance and repair

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ABSTRACT
Within the maintenance activities of non-residential real estate, there is a substantial potential to implement energy efficiency improving interventions that will lead to energy reduction. Besides preserving the technical performance, a focus on the optimization of energy efficiency can contribute to realizing energy saving objectives and lower overall maintenance and energy costs. Besides reflecting on identification and assessment approaches to examine energy efficiency interventions, a dynamic assessment tool was developed with which maintenance scenarios can be assessed in which improvement interventions are included. By the use of a case study into the City Hall of Nijmegen the assessment tool has been verified and assessment has shown that for this specific case cost effectively energy can be reduced.

Keywords: energy efficiency, building maintenance and repair, corporate real estate management, System Dynamics, Monte Carlo Analysis

INTRODUCTION
In the Dutch non-residential building stock there is a large energy saving potential (Daniels & Farla 2006; Schneider & Steenbergen 2010; Menkveld & Van Den Wijngaart 2007). Besides the reduction of energy consumption and consequently carbon emission being vital to mitigate climate change, the potential also implicates a large potential financial gain. Nonetheless, the potential is not exploited due to a lack of commitment to energy reduction, the financial gain for corporate organisations being relatively low (Högberg 2011; Kulakowski 1999) and the presence of practical barriers. Building maintenance is an existing activity within corporate property management that offers possibilities to improve property energy efficiency and so reduce the use of energy (Agentschap NL 2010). With the aim to contribute to solving the problem of unexploited opportunities to reduce energy consumption, the following research questions were posed:
How can the opportunities to improve energy efficiency within maintenance activities of existing non-residential property be exploited?
RQ1: How can building maintenance & repair activities improve property energy efficiency?
RQ2: How can energy efficiency improvement opportunities be identified?

RQ3: How can identified improvement opportunities be assessed?

METHODS

Data collection

Extensive literature review has been carried out to provide knowledge on and data within the areas of property management and energy management. Journals and magazines in the fields of facilities management, real estate management, environmental management, energy policy, energy economics and the built environment where reviewed. Interviews with experts in the consultancy sector have been instrumental in supporting the scientific knowledge gained from literature with empirical knowledge. Besides literature review and expert interviews, a case study was performed into the City Hall of Nijmegen. The purpose of the case study was to 1) verify the dynamic assessment tool that was developed by the use of System Dynamics and 2) to analyse what for the specific case the effects of energy efficient maintenance are. In the end, interviews were conducted with civil servants within the maintenance department of the municipalities of Nijmegen, 'S Hertogenbosch and Eindhoven to verify the assessment tool and case study results.

System Dynamics

System Dynamics (SD) is a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems and is used in this research to develop a tool that aids decision-making. SD is applied as the main methodology in developing a dynamics assessment tool because its ability to simulate behaviour of multiple interdependent and dependent components and its ability to handle much quantitative information, resulting in outcomes that are easy to read and interpret and so consequently can support decision making. A basic principle of System Dynamics is its ability to simulate a system over time using stocks and flows, which are influenced by variables.

Monte Carlo Sensitivity Analysis

Modelling future behaviour by the use of System Dynamics is inevitably linked to making assumptions; these assumptions can be wrong. Therefore, testing the effects of deviant behaviour regarding the results and conclusions is very important. Sensitivity analysis asks whether conclusions change in ways important to the initial purpose when assumptions are varied over the plausible range of uncertainty (Sterman 2000). In this research, this process is lead by Monte Carlo analysis (MCA). MCA is a variance-based sensitivity testing method that builds models by substituting a range of values for the parameters that are uncertain and simulating the model subject to the analysis using these different range of values.

FINDINGS

Literature study and expert interviews

Energy efficient building maintenance

Property energy efficiency can be defined as functioning in the best possible manner without waste of energy. Improvement of energy efficiency can be realised by implementing measures regarding the building service systems and building envelope with the aim to eliminate waste of energy (Hertzsch et al. 2012). For corporate bodies that own non-residential property, building maintenance and repair (BMR) is a non-core business activity in which minimum effort is expected to realize the required functionality by conserving the technical performance of the property. Traditionally, replacement of elements occurs when components' lifetime has ended, preventative maintenance is performed to ensure components achieve their expected lifetime (Stanford 2010). Building maintenance can improve property energy efficiency within existing maintenance activities (i.e. preventative maintenance of service systems and replacement of service systems and building elements) and by adopting new type of activities (i.e. commissioning, insulation and additional placement of elements). In figure 1 a comparison between the traditional BMR strategy and the energy efficiency focused strategy is shown. The maintenance schedule, in which maintenance activities are planned in advance, offers a large opportunity to involve energy efficiency improving measures within BMR (Agentschap NL 2010). The identification of opportunities and assessment of improvement measures are required before deciding what interventions to implement.

Traditional BMR	Energy efficient BMR
Aim: Conservation of technical functionality	Aim: Conservation of technical functionality and optimization of energy efficiency
• Preventative maintenance to ensure technical and economic lifetime of service systems and building components • One-to-one replacement of systems and components when technical lifetime has ended	• Preventative maintenance to ensure technical and economic lifetime of service systems and building components, and to optimize energy efficiency • Replacement of systems and components when or before technical lifetime has ended with energy efficient solution • Placement of new systems and components including insulation if this can improve energy efficiency

Figure 1– Comparison of traditional and energy efficient building maintenance and repair

Identification approaches

The process of identifying improvement measures comprises the identification of inefficiency, components subject to improvement and technical solutions. The lack of information on the energy consumption of a property and thus the lack of information on the energy performance prevent owners from identifying a saving opportunity. Identifying improvement opportunities goes accompanied by specific technical knowledge of the building systems and elements. Although building operators have sufficient knowledge on the building characteristics, it can be questioned whether they are aware of the newest technologies and solutions concerning energy efficiency. Note that a large part of organisations rely on external contractors when it comes to maintenance of property, so specific technological knowledge is often not available in-house and organisations rely on the technical knowledge of their contractors or consultants concerning improvement of their property performance. The identification of the right opportunities of interest for assessment is crucial to maximize efficiency improvement, what means that in the identification phase having access to sufficient information about the property of subject is essential.

Opportunity assessment methods

Assessment of opportunities should provide insight in the impact of the interventions concerning both finance and benefits such as reduced carbon footprint, increased environmental quality, improved sustainability ratings, a better corporate image, and possibly increased asset value. The assessment of technical solutions that can improve energy efficiency in current practice often consists solely of financial valuation by determining the simple payback period of energy savings regarding the investment cost. This method ignores the time-value of money and energy cost savings that occur after the payback period. A more sophisticated valuation method is Life Cycle Costing (LCC) together with the discounted cash flow (DCF) method that supports calculating the Net Present Value (NPV) of an improvement measure. Considering that energy efficiency improvements are an increment to maintenance activities that are already scheduled, replacement of a component by an energy efficient solution can be assessed by calculating the Net Present Value of all incremental costs or income regarding the current building component. A positive Net Present Value indicates a higher value for the energy efficient solution what means that implementation of this solution will, over its total lifetime, lead to cost savings.

Multiple problems arise regarding the assessment of improvement measures. First of all, multiple solutions are possible to eliminate energy inefficiencies, what means that for an entire building, multiple combinations of solutions are possible. Furthermore, the measures can be assessed using multiple criteria and valuation methods, of which more sophisticated financial valuation methods require more complex calculations. Valuation of measures is also influenced by environmental factors such as price increases. Another problem within current assessment approaches is the isolation of improvement measures, while the measures are part of a range of expenditures. Especially when improvement measures are considered as a part of maintenance activities, insight in all maintenance expenditures is required to make decision on the complete overview of costs. The above problems hamper sophisticated assessment of measures and therefore, a support tool is needed that provides help in performing the assessment of a combination of interventions.

Dynamic assessment tool

Functionality

A dynamic assessment tool was developed to aid organisations in assessing energy efficient maintenance scenarios. By the use of Vensim PLE Plus, an assessment tool was created that separates specific input (from a case) from the analysis method and output, what aids structuring and managing data and information. The basic elements of the tool consist of a calculation model and a user interface. Via the user interface, input can be given and output is visualized. This core principle can be seen in figure 2.

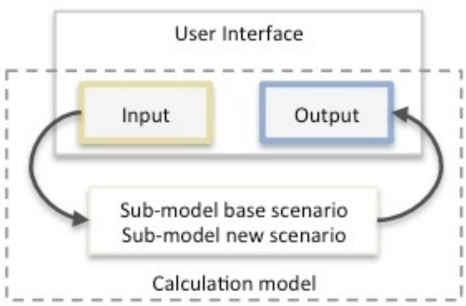

Figure 2 – Core principle of the assessment tool

The aim of the model is to assess maintenance activities regarding its financial effects and energy performance effects; therefore, assessment criteria regarding this aim were determined. The three main criteria considered the most important to aid decision-making are 1) total energy and maintenance expenditures, 2) energy savings and 3) carbon footprint. Besides these three assessment variables, multiple other parameters are used in the model either to support the calculations. SD aids in structurally describing these interrelated variables. To compare the standard or base strategy to BMR with a new strategy in which energy efficient measures are integrated, scenario thinking is applied. Scenario analysis is used in the assessment tool by 1) developing two sub-systems in by the scenarios can be run simultaneously and consequently compared. Both sub-systems need to import external data relating to the case that is been assessed. Besides the two sub-systems, 2) the ability is created to simulate the model under different circumstances by varying parameter values. Not only can the tool be adjusted to align with specific case characteristics e.g. by adjusting initial use of energy and initial energy prices, but also can the model be simulated by varying economic factors that indicate price increase in inflation, maintenance cost, electricity and gas price. The input and output variables can be found in figure 3.

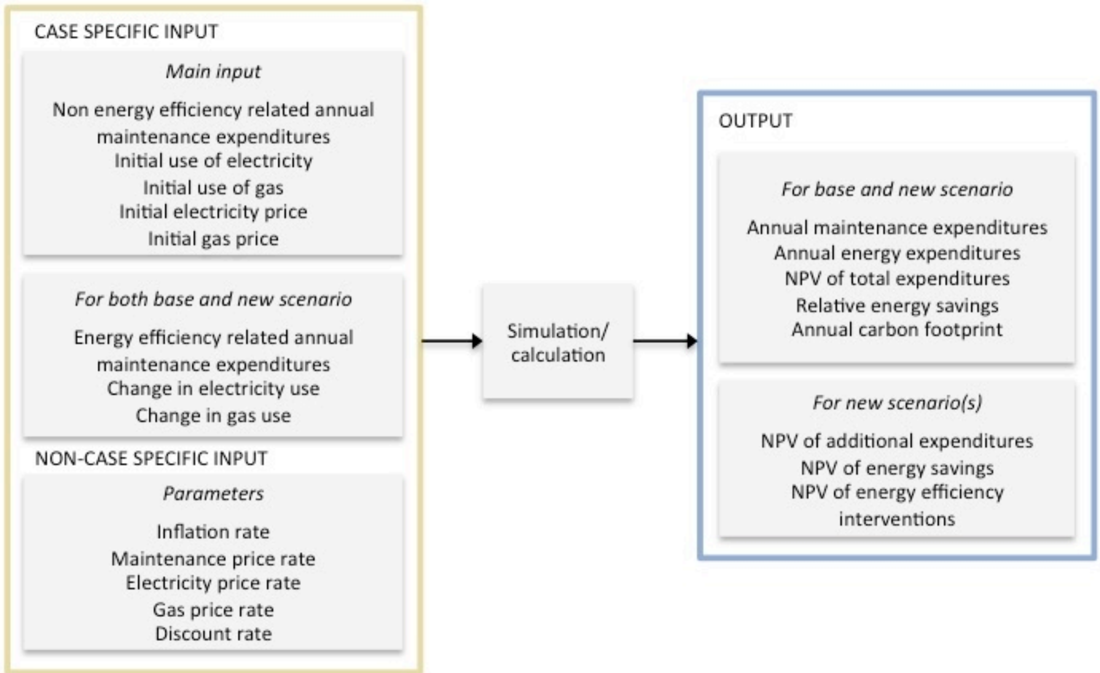

Figure 3 – Assessment tool in and output

The financial valuation method that is used in the model is the discounted cash flow method, translated into Net Present Value (NPV). The NPV discounts cash flows back to the present value what enables comparing cash flows that occur on different moments in time. The System Dynamics software Vensim offers predefined formulas to aid in using NPV calculations. The NPV of the energy and maintenance expenditures for both strategies are calculated to enable comparison of the total value of the two approaches. Additionally for the new scenario, the NPV of the additional maintenance expenditures regarding the base scenario and the NPV of the energy expenditure savings are calculated. The sum of the two latter represents the NPV solely of the energy efficiency interventions. The dynamic nature of the assessment tool accrues from the possibility to adjust multiple variables, depending on the tool user environment. Figure 4 shows the core part of the calculation model used for both sub-systems.

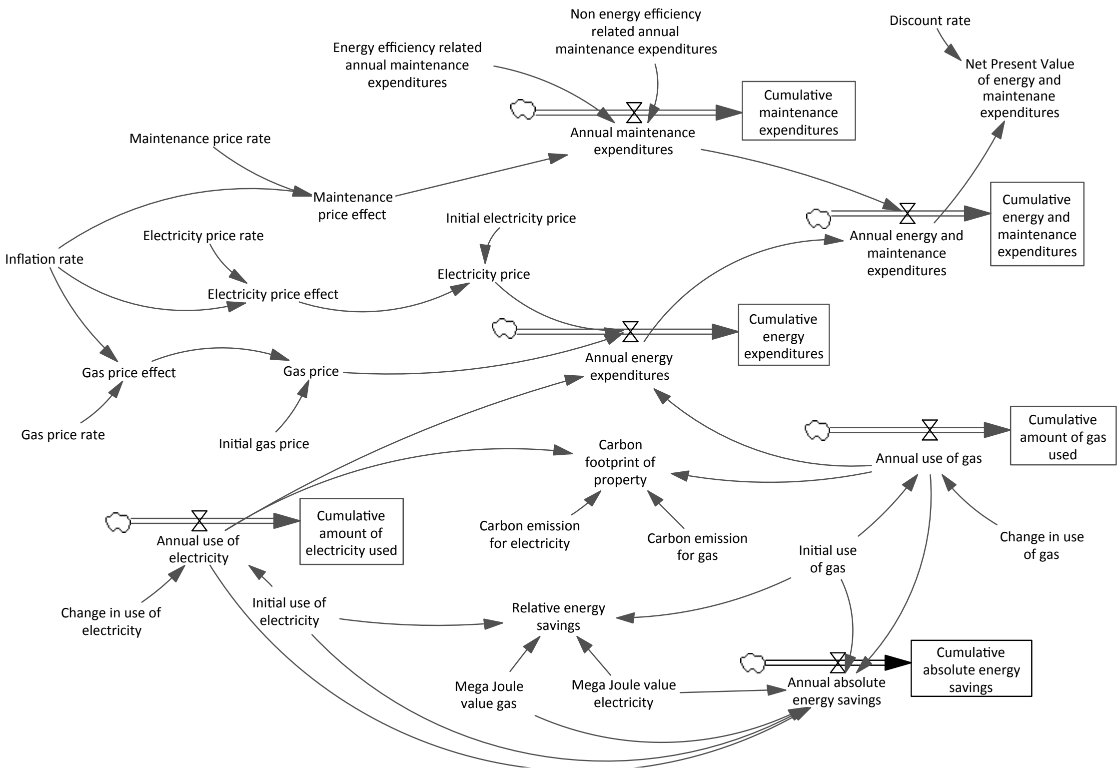

Figure 4 – System Dynamics calculation model

Case study

The assessment tool is tested using a case study into the City Hall of Nijmegen, the Netherlands, for which nine efficiency improvement interventions were determined. The interventions were identified using former EPA-U documents, by the use of information obtained from the current maintenance schedule and based on expert input. Consequently, annual cash flows and projected energy savings were listed for a base scenario and for the new scenario in which the interventions were implemented. This means that all maintenance cost during the lifecycle of a component were involved.

The listed cash flows and energy savings were linked to the assessment tool, and the required parameter values were determined. Besides entering the case specific variables including, initial use of energy and initial energy prices, the inflation rate (2%), maintenance price rate (0.5%), electricity price rate (1%), gas price rate (4%) and discount rate (5%) were entered. Consequently, the model was simulated over a period of 20 years. This time period represents a part of the buildings lifecycle in which many maintenance activities take place, including cost and savings made associated with the interventions. The assessment tool shows that over a period of 20 years, the net present value of the energy efficient scenario is 5% higher in value than the old maintenance plan, as can be seen in figure 5 (€10.5M and €10M).

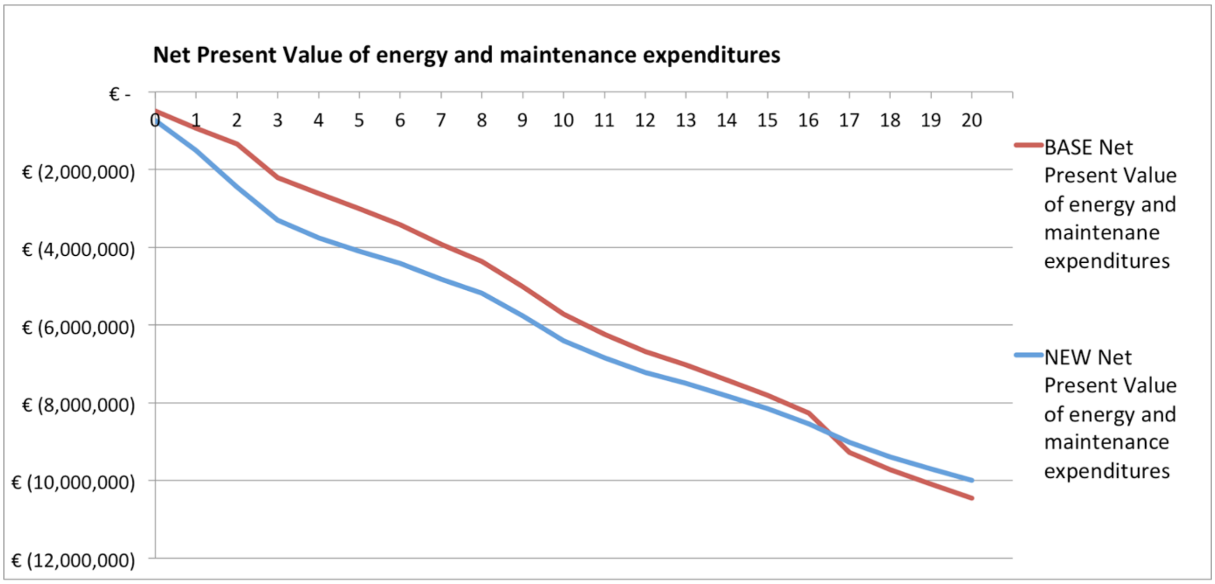

Figure 5 – Case study assessment outcome

The energy consumption and carbon emission of the new scenario, decreases compared to the base scenario consecutively 25% and 20%. If the NPV over 20 years are calculated back to the price per square meter per year, one can find that by spending €2,- (i.e. €16,- instead of €14,-) more on maintenance activities, €4,- is saved on the energy bill (i.e. €17,- instead of €21,-). This together results in €2,- savings on total energy and maintenance expenditures per square meter per year (i.e. €35,- instead of €33,-).

Monte Carly Sensitivity Analysis (MCA) was performed to test whether substantial differences in the NPV of the base scenario and the new scenario occur what might lead to other decision-making. Figure 6 shows the parameters involved in the MCA, including the uncertainty distribution, mean value and uncertainty range. Thousand iterations were run, what means that thousand random sets of parameter values within the depicted range were used to run the model.

Parameter	Distribution	Mean	Range
Inflation rate	Triangular	2	1-3%
Maintenance price rate	Triangular	0.5%	-0.5%-1.5%
Electricity price rate	Triangular	1%	2-3%
Gas price rate	Triangular	4%	3-5%
Uncertainty on change in use of electricity	Uniform		0.8-1.2
Uncertainty on change in use of gas	Uniform		0.8-1.2

Figure 6 – Monte Carlo analysis parameter values

The boxplot as shown in figure 7 including analysis shows that for none of iterations run in the MCA, the NPV of the base scenario is higher than in the new scenario. This indicates that for this specific case assessment, no other decisions would be made if the NPV is the leading indicator. Besides this, the spread of the new scenario NPV MCA outcome is lower, what means that the uncertainty on the size of cost is lower.

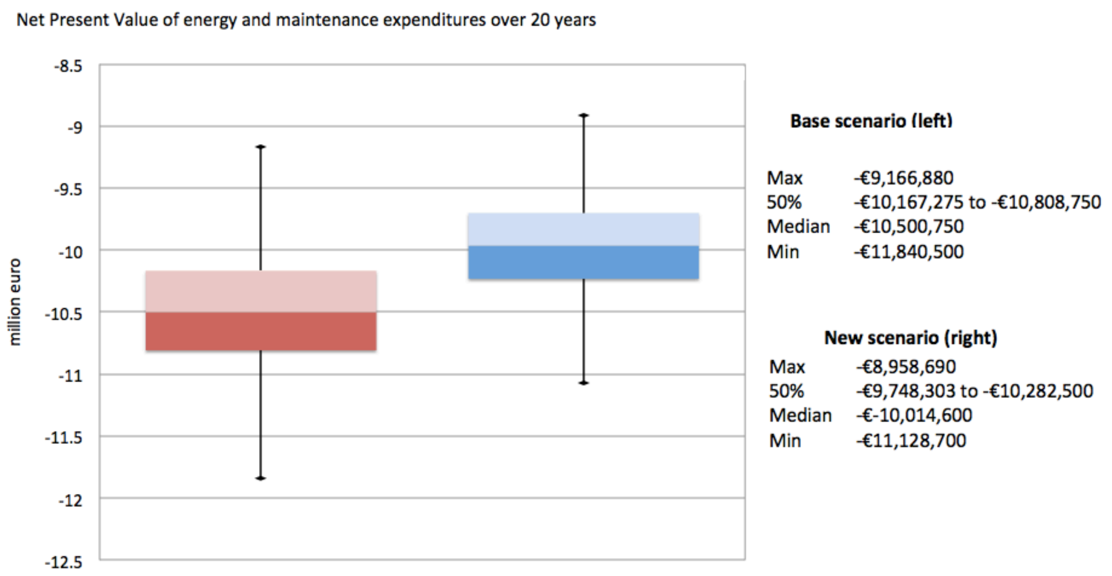

Figure 7 – Boxplot of sensitivity analysis outcome: NPV of annual energy and maintenance expenditures

Conclusion

The development of a dynamic assessment tool aims helping organisations in assessing energy efficient maintenance scenarios that include multiple energy efficiency interventions as a part of other maintenance activities. The tool provides organisations a method with which multiple maintenance scenarios can be analysed. The tool was verified by expert interviews in the municipal sector and consultancy sector, which notice that the use of NPV provides useful insights in energy efficiency improvement measures.

Main research question: How can the opportunities to improve energy efficiency within maintenance activities of existing non-residential property be exploited?

This research has resulted in determining that maintenance activities can contribute to energy efficiency by embedding energy improving interventions within the existing maintenance planning. The steps to examine specific energy efficient solutions comprise of finding energy inefficiencies, determining inefficient systems or components and consequently technical interventions. Possible assessment criteria are identified of which financial assessment criteria are discussed in more detail, leading to the advise to use Life Cycle Cost Analysis and the discounted cash flow method to evaluate improvement measures. To support the assessment phase, a dynamic assessment tool was provided that supports the assessment of multiple improvement interventions as a part of a complete maintenance schedule. These research results provide useful guidance in exploiting opportunities within maintenance activities to reduce energy consumption.

DISCUSSION

Practical implications

The findings of this study have a number of important implications for future practice. Three courses of action are suggested to all parties concerned with corporate real estate management, and specific courses of action are suggested to corporate organisations, advisory companies and national government (i.e. stakeholders of the research problem). Firstly, organisations concerned with property management are recommended to gain insight on the actual energy consumption. Any barriers or split incentives regarding property cost and energy cost should be eliminated. Secondly, the use of the simple payback period calculation as a means to assess the profitability of single improvements is recommended to reconsider. Instead, the use of life cycle costing analysis can be used. Thirdly, organisations are, besides individual assessment of improvements, recommended to assess a combination of improvements as a part of a complete maintenance scenario while taking future uncertainties into account. This method of assessment is a more holistic approach and aids decision-making by providing a complete overview of the possible range of costs. Tools, such as the assessment tool developed in this research, can help organisations in performing this more complex assessment.

Following implications arising from the research results that are applicable to property management within organisations. The case study has shown that within maintenance activities cost effectively energy reductions can be realized. This implicates that organisations should consider whether for their own property, likewise results are possible. Many organisations have the strategic aim to reduce energy, although these aims are not yet translated into effective practical solutions. Embedding energy interventions within existing processes such as property maintenance, poses to be a sustainable solution to fulfill saving objectives. For consultancy companies there is an important role when it comes to aspects concerning sustainability such as energy reduction; many organisations heavily rely on consulting expertise. This research pledges advisory companies to adopt a proactive role in providing insight to clients on benefits and drawbacks of improving energy efficiency and finding tailor-made solutions. Lastly, one implication is given that concerns government. Because many practical barriers are faced in the improvement process, organisations are not compliant to end-result based legislation. Rather, government should focus on compelling conditions that ease or are an essential part of the improvement process.

Limitations and further research

The following limitations were identified that influence the result and generalizability of the research. First of all, the assessment tool is supported by System Dynamics and made using Vensim software; no other methods have been tested. This indicates that other methods possibly provide a more accurate or easier to use assessment tool. Besides this, the assessment tool is verified by the performance of a single case study. Although the case study proves the functionality of the assessment tool for this specific case, multiple case studies should be performed to identify if the tool is actually robust. A suggestion for further research is to perform more case studies within various sectors to test the tool. The case study was not aimed at gaining generalizable data regarding maintenance cost or energy savings. However, the tool can possibly be used to gather this type of data. Future research can focus, besides the verification of the tool, on performing case studies with a large sample size (i.e. >10). In this way, for example for one specific market sector can be determined whether energy can be reduced cost-effectively by embedding energy efficiency interventions within maintenance activities. Secondly, expert interviews were performed as a means to gather data in the exploration phase and to verify the assessment tool and case study data. The technique of interview is not free from bias, especially if the interviewer is one single researcher. Ideally, the research is supported by the use of a statistical data collection method. Future research can therefore for example use survey research to verify the assessment tool to eliminate the drawbacks of interview research.

The following other topics have been suggested for further research based on the findings of this research. This research pointed out that energy reduction of non-residential property possibly goes accompanied by multiple benefits of which not all are included in the assessment tool. Further research is suggested to examine how other impacts can be translated into measurable variables. This can lead to an extension of the assessment tool. The current research was not designed to evaluate for which real estate sector the new approach to building maintenance is the most suitable or will lead to the highest benefits. A suggestion for further research is to investigate building operators views on the energy efficient maintenance approach by the means of survey research within specific sectors.

REFERENCES

Agentschap NL, 2010. *Verdienen met duurzaam onderhoud*, Utrecht, the Netherlands.
Daniels, B.W. & Farla, J.C.M., 2006. *Optiedocument energie en emissies 2010 / 2020*, Bilthoven, the Netherlands.
Hertzsch, E., Heywood, C. & Piechowski, M., 2012. A methodology for evaluating energy efficient office refurbishments as life cycle investments. *International Journal of Energy Sector Management*, 6(2), pp.189–212.
Högberg, L., 2011. *Incentives for energy efficiency measures in post-war multi-family dwellings*. Royal Institute of Technology Kungliga Tekniska Hogskolan.
Kulakowski, S.L., 1999. *Large organizations' investments in energy-efficient building retrofits*, Berkeley, United States of America.
Menkveld, M. & Van Den Wijngaart, R.A., 2007. *Verkenning potentieel en kosten van klimaat en energiemaatregelen voor Schoon en Zuinig*, The Netherlands.
Schneider, H. & Steenbergen, P., 2010. *Marktstudie CO2 - besparingpotentieel ESCo's in utiliteitsbouw*, Delft, the Netherlands.
Stanford, H.W., 2010. *Effective Building Maintenance - Protection of Capital Assets*, The Fairmont Press, Inc.
Sterman, J., 2000. *Systems Thinking and Modeling for a Complex World*, Irwin McGraw-Hill.

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From a societal perspective, energy reduction is vital in mitigating climate change. In the corporate real estate market, energy saving and profitable business can go hand in hand. However, fundamental and also many practical barriers need to be overcome to make business out of the energy saving potential. A weighted balance between academic and empirical research can lead to solutions that will bring seizing opportunities closer to reality.

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Aug 2012 – Dec 2012	Exchange semester National University of Singapore
Feb 2013 – Aug 2013	Graduation internship Royal HaskoningDHV

Appendix 10 – Dutch summary

HET BENUTTEN VAN DE ENERGIEBESPARINGKANSEN IN DE UTILITEITSBOUW
Een nieuwe strategie voor onderhoud en beheer

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SAMENVATTING

Het onderhoud en beheer van utiliteitsgebouwen biedt kansen om met minimale extra inspanning energie reducerende maatregelen te treffen. Energiebesparingsdoelstellingen kunnen worden gerealiseerd door naast instandhouding van het vastgoedobject ook te sturen op optimalisatie van de energie efficiëntie van het gebouw. Dit onderzoek reflecteert op verschillende aanpakken om verbetermaatregelen te identificeren en te beoordelen. Hiervoor is een dynamisch rekenmodel ontwikkeld waarmee voor onderhoudsscenario's inzicht kan worden gecreëerd in verwachte energiebesparingen, onderhoud- en energiekosten.

INLEIDING

De Nederlandse utiliteitsbouw kent een groot energiebesparingspotentieel (Daniels & Farla 2006; Schneider & Steenbergen 2010; Menkveld & Van Den Wijngaart 2007). Niet alleen is verminderen van energieverbruik cruciaal is om het klimaatprobleem tegen te gaan, ook kunnen verminderingen tevens resulteren in kostenbesparingen. Desalniettemin, vanwege een groot aantal barrières, een gebrek aan overtuiging, en de relatief kleine kostenbesparing verzaken organisaties in het nemen van maatregelen. Binnen het onderhoud en beheer van gebouwen zijn verschillende kansen om maatregelen in te bedden (Agentschap NL 2010). Dit onderzoek heeft als doel bij te dragen aan het vinden van manieren om deze kansen te benutten. Binnen het ontwerp van het onderzoek is de volgende onderzoeksvraag gesteld:

Hoe kunnen binnen het onderhoud en beheer van utiliteitsgebouwen kansen benut worden om energie efficiëntie vergrotende maatregelen te nemen?

ONDERZOEKSMETHODE

Kennis is vergaard door extensief literatuuronderzoek en exploratieve interviews met professionals werkzaam in de adviesindustrie. Een dynamisch rekenmodel is ontwikkeld aan de hand van de System Dynamics methode. Dit model is ontwikkeld en getoetst door middel van een case studie naar het Stadhuis van Nijmegen. Tevens is een Monte Carlo Analyse toegepast om de gevoeligheid van modelresultaten te testen. Vervolgens zijn expert interviews gehouden om het gebruik van het model en de resultaten te verifiëren.

BEVINDINGEN

Literatuurstudie en expert interviews

Energie efficiënt gebouwonderhoud

Een energie efficiënt gebouw kan worden gedefinieerd als een gebouw dat functioneel optimaal presteert zonder energie te verspillen. De energie efficiëntie kan vergroot worden door maatregelen te nemen aangaande de installaties en/of gebouwschil (Hertzsch et al. 2012). Het beheren van corporate vastgoedobjecten is een secundaire bedrijfsactiviteit waaraan doorgaans minimale uitgaven worden gedaan om het functioneren van het gebouw in stand te houden. Traditioneel onderhoud richt zich op het preventief onderhouden van gebouwelementen waar vervanging plaats vindt als het element het einde van zijn technische levensduur heeft bereikt (Stanford 2010). Figuur 1 laat een vergelijking zien tussen de traditionele onderhoudsstrategie en de nieuwe strategie waarin energie efficiëntie verbeterende maatregelen worden opgenomen. Voordat deze activiteiten daadwerkelijk kunnen worden uitgevoerd, zullen verbetermogelijkheden geïdentificeerd en beoordeeld moeten worden.

Traditioneel onderhoud	Energie efficiëntie gericht onderhoud
Doel: Instandhouding van gebouwkwaliteit	Doel: Instandhouding van gebouwkwaliteit en optimalisatie van energie efficiëntie
• Preventief onderhoud aan installaties en bouwkundige componenten: voorkomen van storingen, waarborgen technische levensduur • Een-op-een vervanging: aan einde technische levensduur	• Preventief onderhoud installaties en bouwkundige elementen: voorkomen van storingen, waarborgen technische levensduur, optimalisatie energie efficiëntie • Vervanging van elementen: vervanging door energie efficiënte technologie aan einde technische levensduur of eerdere vervanging indien mogelijke verbetering energie efficiëntie • Plaatsing van nieuwe installaties of componenten (incl. Isolatie): indien mogelijke verbetering energie efficiëntie

Figuur 1– Vergelijking tussen traditioneel en op energie efficiëntie gericht onderhoud

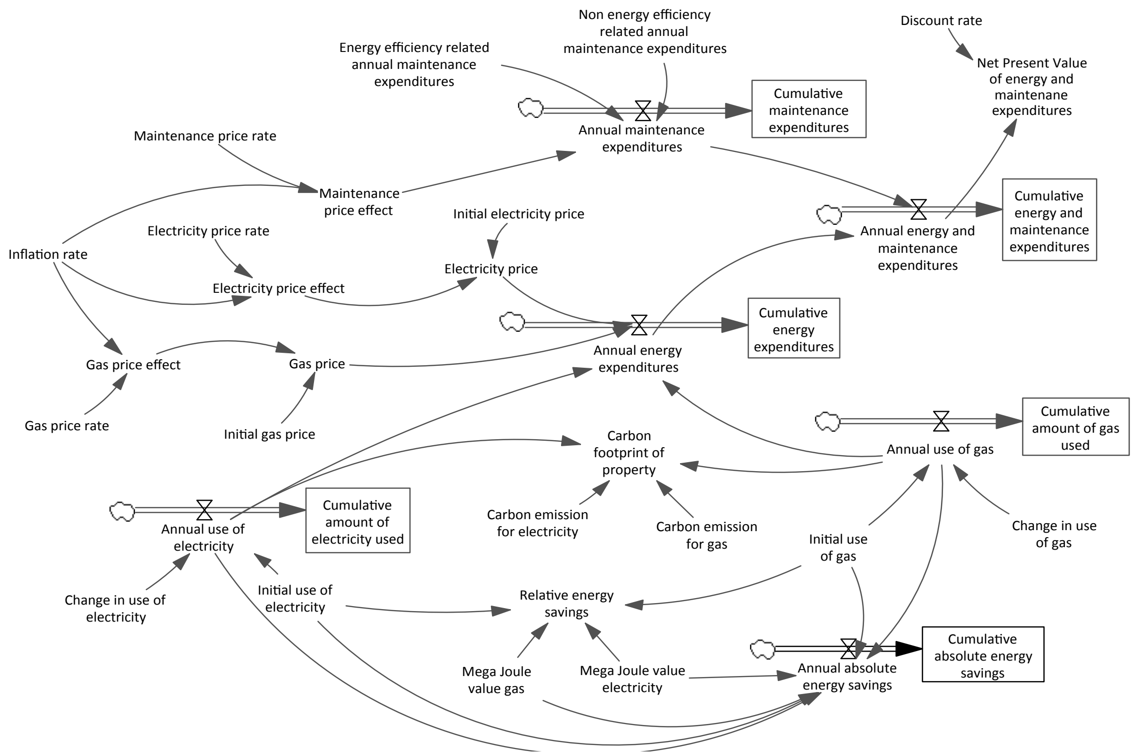
Identificatie en beoordeling van verbetermaatregelen

Maatregelen die de energie efficiëntie verbeteren kunnen worden geïdentificeerd door middel van het monitoren van het energiegebruik, door het beoordelen van de elementen in een gebouw en door kennis over technologieën toe te passen. In dit proces is het inzicht in het werkelijk energieverbruik, de beschikbaarheid over accurate informatie over het gebouw en de beschikbaarheid over state-of-the-art kennis van groot belang. Met betrekking tot het identificeren van maatregelen zijn veel organisaties afhankelijk van expertise van adviesorganisaties. Op het moment dat verschillende verbeterpunten en specifieke maatregelen of mogelijkheden zijn geselecteerd, volgt beoordeling van de maatregelen zodat een keuze gemaakt kan worden over welke maatregelen passen binnen de kaders van de organisatie. Naast beoordeling van financiële haalbaarheid kunnen andere effecten, zoals een verbeterd binnenklimaat, een vergroot bedrijfsimago of verbeterde duurzaamheidscertificaten, meegenomen worden. Aangaande de financiële beoordeling bieden rekenprincipes zoals Lifecycle Costing in combinatie met het terugrekenen van kosten en baten naar de netto contante waarde een goede basis, in tegenstelling tot het gebruik van de simpele terugverdientijd. Naast dat beoordelen van een combinatie aan verbetermaatregelen lastig is doordat meerdere scenario's mogelijk zijn, worden binnen huidige beoordelingen vaak maatregelen in isolatie behandeld zonder overige kosten aan onderhoud en energie mee te nemen. Het berekenen van lange termijn effecten wordt hiernaast bemoeilijkt doordat rekening dient te worden gehouden met mogelijke prijsstijgingen in energie, in onderhoud en ten gevolge van inflatie.

Dynamisch rekenmodel

Functionaliteit

Een dynamisch rekenmodel (figuur 2) is ontwikkeld ter ondersteuning van het beoordelen van onderhoudsscenario's waarbinnen energiebesparingsmaatregelen genomen zijn. Het rekenmodel is gebaseerd op System Dynamics en ontwikkeld met behulp van het software pakket Vensim PLE Plus. De gebruiker kan de jaarlijkse kosten die behoren tot een 'basis' en 'nieuw' scenario koppelen aan het rekenmodel, inclusief de verwachte verschillen in het energieverbruik. Het model berekent, aan de hand van ingegeven waarden, de netto contante waarde van de verschillende scenario's en maakt naast financiële cijfers de totale energiebesparingen en CO2-uitstoot inzichtelijk.



Figuur 2 – System Dynamics basisgedeelte van het rekenmodel (in het Engels)

Case studie

Aan de hand van een case studie naar het Stadhuis van Nijmegen is het rekenmodel getest. Het oude onderhoudsplan van het Stadhuis is gebruikt als basis scenario. Een nieuw onderhoudsscenario is ontwikkeld door het inbedden van de lifecycle kosten aangaande negen energiebesparingsmaatregelen in het oude onderhoudsplan. Vervolgens heeft het rekenmodel beide scenario's gesimuleerd over een periode van 20 jaar, waarin het jaarlijkse inflatiepercentage (2%), de onderhoudsprijsstijging (0,5%), de electriciteitsprijsstijging (1%) en gasprijsstijging (4%) zijn meegenomen. De gebruikte discontovoet bedraagt 5%. Het rekenmodel laat zien dat de waarde van het nieuwe onderhoudsscenario 5% hoger is dan het oude scenario (€10,5 miljoen tegenover €10 miljoen). Het jaarlijkse energiebesparingspercentage bedraagt 25% en de CO2-uitstoot is jaarlijks 20% lager. Een sensitiviteitsanalyse met behulp van Monte Carlo Analyse laat zien dat de netto contante waarden van de scenario's niet dusdanig verschillen dat zal leiden tot andere beslissingen, daarnaast biedt het nieuwe scenario minder onzekerheid in toekomstige kosten.

DISCUSSIE

Implicaties

De resultaten van het onderzoek heeft verscheidene implicaties. Organisaties wordt geadviseerd om te onderzoeken of een strategische verandering in onderhoudsdoelstellingen kan bijdragen aan het behalen van energiebesparings-doelstellingen. Hierbij is het zeer belangrijk om inzicht te hebben in het werkelijke energieverbruik, toegang te hebben tot complete en juiste informatie en kennis in huis te hebben of te halen over technologieën. Hiernaast worden organisaties geadviseerd om verbetermaatregelen in de context van totale energie- en onderhoudskosten te bekijken zodat een realistisch overzicht wordt gecreëerd. Het ontwikkelde dynamische rekenmodel kan hierbij helpen. Adviesbureaus die actief zijn op het gebied van duurzaamheidsadvies en gebouwbeheer wordt verzocht een actieve rol aan te nemen met betrekking tot het inzichtelijk maken van kansen en resultaten van verbetermaatregelen. Een rol voor de overheid wordt in mindere mate gezien in het verplicht stellen van het behalen van energiebesparingsdoelstellingen, maar in meerdere mate in het verhelpen van barrières en het verplichten van tussenstappen zoals inzicht verkrijgen in energie consumptie.

Verder onderzoek

Het dynamische rekenmodel dient verder geverifieerd te worden door meerdere case studies uit te voeren. Hiernaast kan een onderzoek naar de kosten efficiëntie van de nieuwe onderhoudsstrategie uitgevoerd worden door het rekenmodel te gebruiken om een steekproef van circa tien panden te doen. Statistische onderzoeksmethoden met behulp van enquête onderzoek kan gedaan worden met betrekking tot het verzamelen van waardeoordelen over het rekenmodel of om voorkeuren met betrekking tot uitbreidingen van het model in kaart te brengen.

REFERENTIES

Agentschap NL, 2010. *Verdienen met duurzaam onderhoud*, Utrecht, the Netherlands.

Daniels, B.W. & Farla, J.C.M., 2006. *Optiedocument energie en emissies 2010 / 2020*, Bilthoven, the Netherlands.

Hertzsch, E., Heywood, C. & Piechowski, M., 2012. A methodology for evaluating energy efficient office refurbishments as life cycle investments. *International Journal of Energy Sector Management*, 6(2), pp.189–212.

Menkveld, M. & Van Den Wijngaart, R.A., 2007. *Verkenning potentieel en kosten van klimaat en energiemaatregelen voor Schoon en Zuinig*, The Netherlands.

Schneider, H. & Steenbergen, P., 2010. *Marktstudie CO2 - besparingpotentieel ESCo's in utiliteitsbouw*, Delft, the Netherlands.

Stanford, H.W., 2010. *Effective Building Maintenance - Protection of Capital Assets*, The Fairmont Press, Inc.

Sterman, J., 2000. *Systems Thinking and Modeling for a Complex World*, Irwin McGraw-Hill.