Energy saving potential for corporate property: system dynamic approach

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Abstract

Within the maintenance activities of non-residential real estate, there is a substantial potential to implement energy efficiency measures leading to the reduction of energy consumption. A focus on the optimization of energy usage can contribute to lowering overall maintenance and energy costs, preserving the technical performance of a building, and realizing energy saving objectives. Therefore a dynamic assessment tool to support an optimal energy usage in a non-residential building was developed. The tool is based on a system dynamic model that has sensitive variables for: two potential maintenance scenarios, external factors, and case specific conditions. In addition, by introducing a case study of Nijmegen City Hall the assessment tool applicability has been shown.

Keywords: sustainable transformation, facility management, corporate real estate management, system dynamics, Monte Carlo analysis

1. 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 significant financial gain. Nonetheless, the potential is not exploited due to a lack of commitment to energy reduction. Mainly due to the relatively low financial gain (Högberg 2011; Kulakowski 1999) compared to total income of corporate organizations 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 to reduce the use of energy (Agentschap NL 2010). With the aim to contribute solving the problem of unexploited opportunities to reduce energy consumption, this paper explores which activities or measures within facility management can be introduced to improve energy efficiency, how to identify the potential for improvement and how to assess the benefits of improving energy efficiency.

1.1 Improving energy efficiency: measures, improvement potential, assessment

Property energy efficiency can be defined as functioning in the best possible manner without waste of energy. Improvement of energy efficiency can be realized 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). Table 1 shows a comparison between the traditional BMR strategy and the energy efficiency focused strategy. 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.

Table 1. Comparison of traditional and energy efficient building maintenance and repair

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	• Preventative maintenance to ensure technical and economic lifetime of service systems and building components, and to optimize energy efficiency
• One-to-one replacement of systems and components when technical lifetime has ended	• 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

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 organizations rely on external contractors when it comes to maintenance of property, so specific technological knowledge is often not available in-house and organizations 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.

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 energy efficient solution can be assessed by calculating the NPV of all incremental costs or income regarding the current building component. A positive NPV 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.

2. Assessment support tool for energy imporvment in non-residential buildings

2.1 System Dynamics and Monte Carlo Analysis

The decision support tool consists of a model that is based on the principles of system dynamics (SD). System

Dynamics (SD) is a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems and it is used in this paper 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 behavior of multiple interdependent and dependent components and its ability to incormporate a large database, resulting in the outcomes that are easy to read and interpret and consequently can support decision making. A basic principle of SD is its ability to simulate a system over time using stocks and flows, which are influenced by variables.

Modelling future behavior by the use of SD is inevitably linked to making assumptions; these assumptions can be wrong. Therefore, testing the effects of deviant behavior 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 paper, this process is lead by Monte Carlo analysis (MCA). In brief, 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.

2.2 Dynamic assessment tool

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. The input is based on case study and macroeconomic data, the data is further analyzed, finally output aids structuring and managing the data and information. The basic elements of the tool consist of a calculation model and a user interface (Fig. 1.).

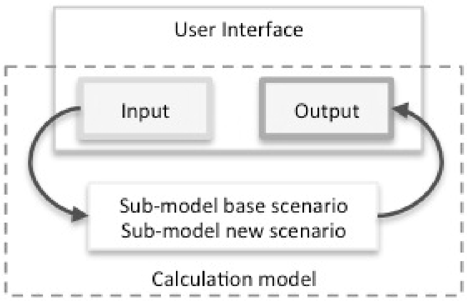

Figure 1. Concept of the assessment tool

Calculation model is based on the previously mentioned SD method and MCA. Furthermore, via the user interface, input can be given and output is visualized. 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: a) total energy and maintenance expenditures; b) energy savings and c) carbon footprint. Besides these three assessment variables, multiple other parameters are used in the model to support the calculations. SD aids in structurally describing these interrelated variables.

In regard to financial part of assessment, the financial valuation method that is used in the model is the DCF, translated into NPV. The NPV discounts cash flows back to the present value what enables comparing cash flows that occur on different moments in time. The SD software *Vensim PLE Plus* offers predefined formulas to aid in using NPV calculations. The NPV of the energy and maintenance expenditures for both strategies are calculated to enable the comparison of the total value of the two scenarios. 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.

In order to compare the standard or base strategy to BMR with a new strategy in which energy efficient measures are integrated, different scenarios has been applied. Scenario analysis is used in the assessment tool by developing two sub-systems reflecting two scenarios that can be run simultaneously and consequently compared. Both sub-systems need to import external data related to the case that is being assessed.

Besides the two sub-systems, the model simulates data under different circumstances by varying parameter values. Therefore, not only that the tool can be adjusted according to the specific case characteristics (e.g. by adjusting initial use of energy and initial energy prices) but also can the model be simulated under the varying economic factors that indicate price increase in inflation, maintenance cost, electricity and gas price. The full description of variables used in the model has been listed below (Tab le 2) and stock and flow model as well (Fig. 2).

Table 2. Variables for base and new scenario calculation 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 CO2/kilowatt hour	Carbon dioxide emission in kilogram per kilowatt hour electricity (0.59686)
Carbon emission for gas	Kilogram CO2/cubic meter of gas	Carbon dioxide emission in kilogram per cubic meter of gas (1.79772)
Carbon footprint of property	Kilogram CO2/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 t0
Initial gas price	Euro/cubic meter of gas	The price of a cubic meter of gas at t0
Initial use of electricity	Kilowatt hour/year	The annual use of electricity at t0
Initial use of gas	Cubic meter of gas/year	The annual use of gas at t0
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
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

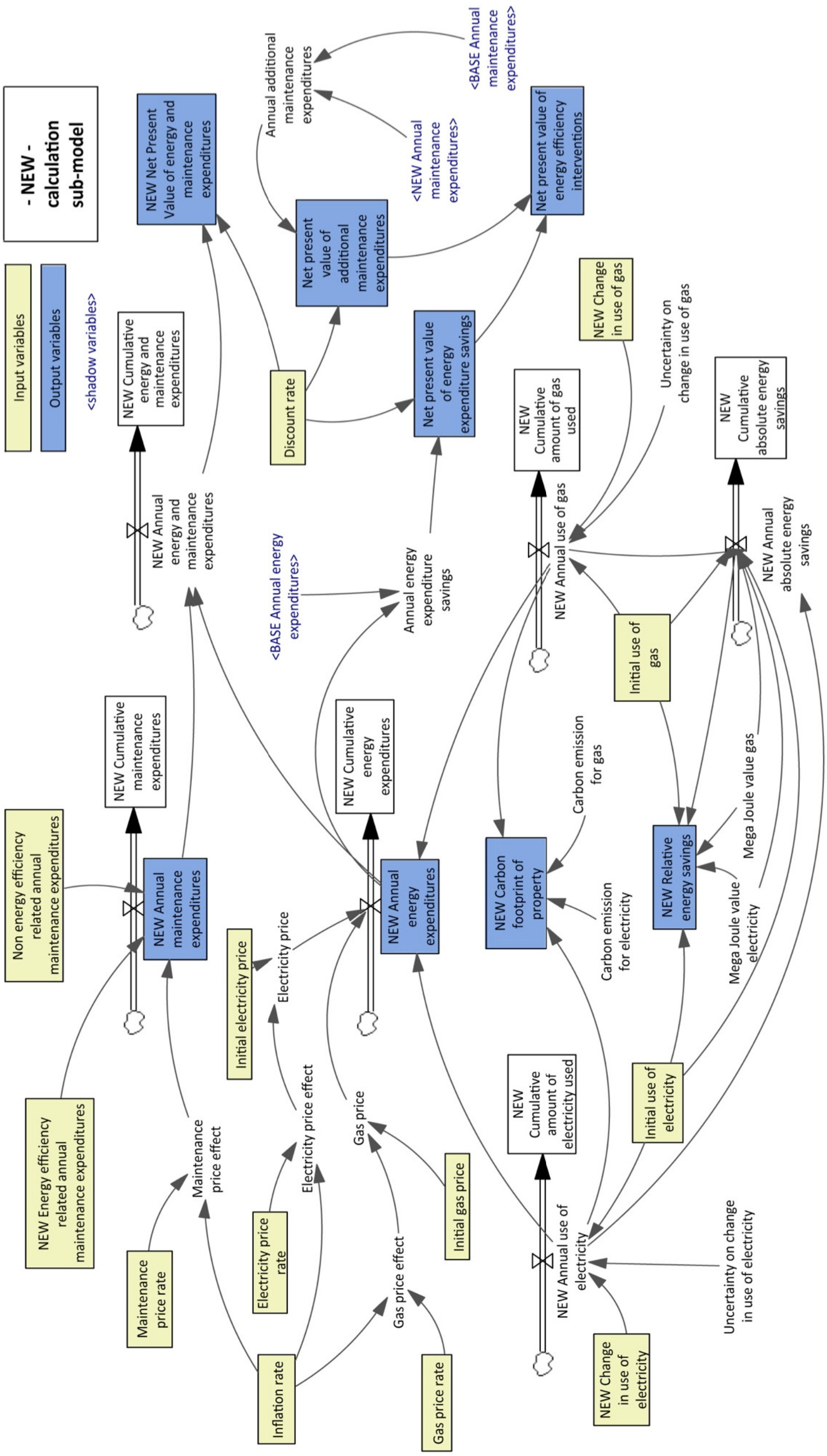

Figure 3. System Dynamics calculation model

3. Results

3.1 Case Study

The purpose of the case study was to justify the use of the dynamic assessment tool that was developed by the SD, and to analyse the effects of energy efficient maintenance for the specific case. In the end, interviews were conducted with civil servants within the maintenance department of the municipalities of Nijmegen, ‘S Hertogenbosch and Eindhoven confirmed a usability of this assessment tool for a particular 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 as well as for the new scenario in which the interventions were implemented. This implies that all maintenance cost during the lifecycle of a component were included.

3.2 Simulation Analysis

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, some general macro economic variables were introduced as well such as the inflation rate (2%), maintenance price rate (0.5%), electricity price rate (1%), gas price rate (4%) and discount rate (5%). Further, the model simulates the period of 20 years. This time period represents a part of the buildings lifecycle in which many maintenance activities would take place, including cost and savings made associated with the interventions. The assessment tool shows that over a period of 20 years, the NPV of the energy efficient scenario is 5% higher in value than the old maintenance plan, as can be seen in figure 4 (€10.5M and €10M). If the NPV over 20 years are calculated back to the price per square meter per year, one can find that by spending €2 (e.g. €16 instead of €14) more on maintenance activities, €4 is saved on the energy bill (e.g. €17 instead of €21). Together this results in €2 savings on total energy and maintenance expenditures per square meter per year (e.g. €35 instead of €33). In addition, the energy consumption and carbon emission of the new scenario, decreases compared to the base scenario consecutively 25% and 20%.

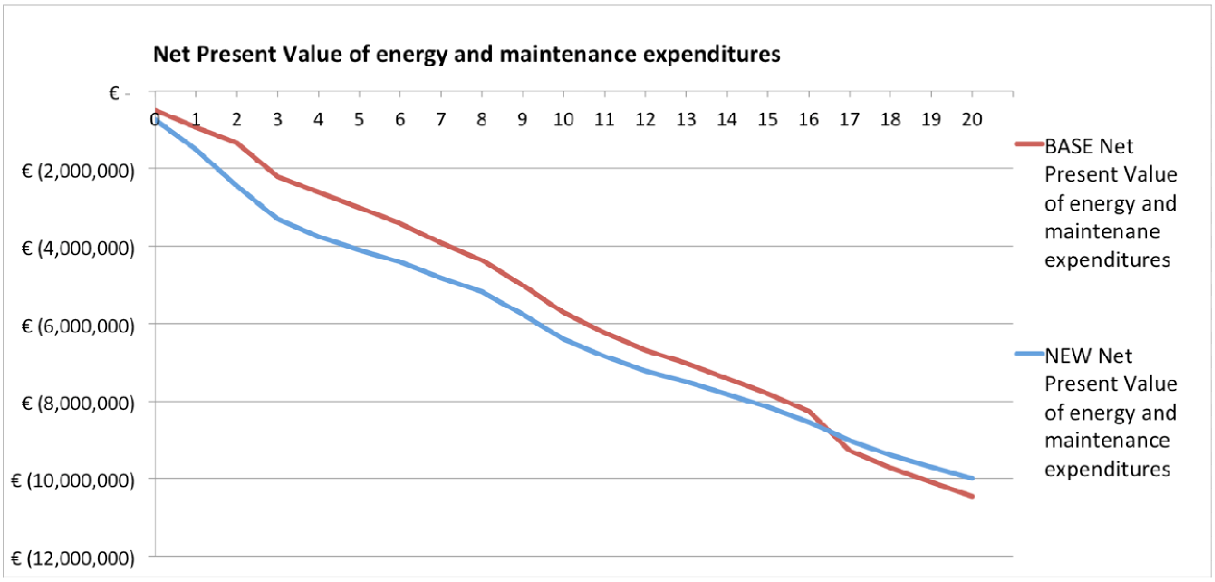

Figure 4. Case study assessment outcome

Further, MCA was performed to test whether substantial differences in the NPV of the base scenario and the new scenario occur and if that might lead to another decision. Table 2 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. The boxplot (Fig. 5.) shows that the iteration runs in the MCA for the NPV are much more favorable for the new scenario than for the base 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, meaning that the uncertainty over the cost spread is lower.

Table 2. Monte Carlo analysis parameter values

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

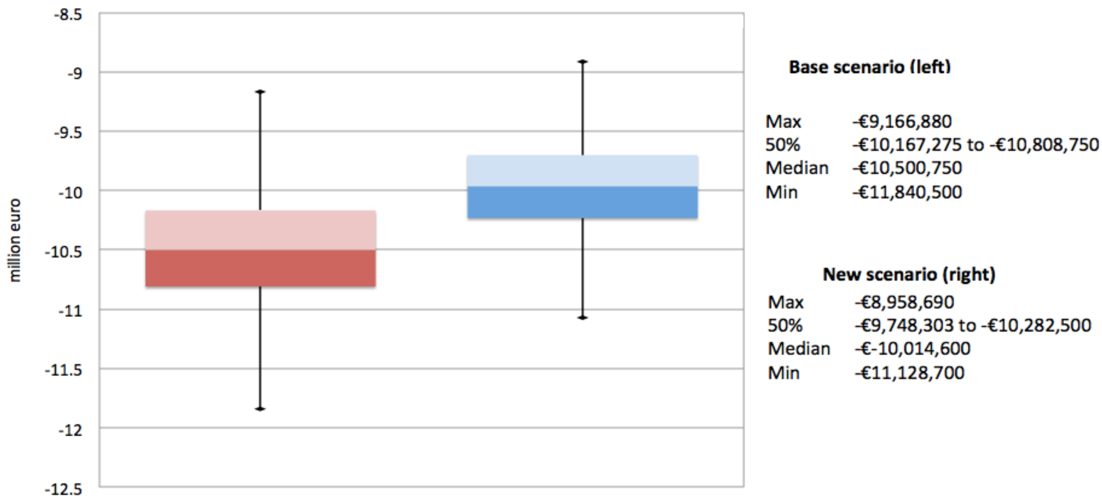

Figure 5. Boxplot of sensitivity analysis outcome: NPV of annual energy and maintenance expenditures

4. Conclusions & Discussion

This paper 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. Thus this paper's results provide useful guidance in exploiting opportunities within maintenance activities to reduce energy consumption.

More specific, an assemssment tool has been developed. This 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 which multiple maintenance scenarios would be the most feasible. Therefore, possible assessment criteria have been identified of which financial assessment criteria are discussed in more detail.

The findings of this paper have a number of practical implications for future practice. Three courses of action are suggested to all parties concerned with corporate real estate management. 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 NPV and LCC 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..

In addiotn, the benefitiary of these suggestions could be one of the named stakeholders: corporate organisations, advisory companies and national government. 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 adviosry companies there is an important role when it comes to aspects concerning sustainability such as energy reduction, this assemsment tool can be use as a platfforme to support their consulting expertise. 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.

The tool was tested by experts in the municipal and consultancy sector, which notice that the use of NPV provides useful insights in energy efficiency improvement measures. In addition, the chosen case study has shown that within maintenance activities cost effectively energy reductions can be realized.

4.1 Limitations and further research

The following limitations were identified that influence the result and generalizability of this paper. First, the assessment tool is tested 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 additional case studies to statistically test the tool. In addition, only the expert interviews were introduced as a mean to gather data to verify the assessment tool. The technique of interview is not free from bias therefore using survey would provide a statistical validation. Also, the tool can be used to gather generic data instead of only case specific. In this way, the tool could be adjusted to support decision regarding one specific market sector for determining energy efficient interventions within maintenance activities. Finally, this paper pointed out that energy reduction of non-residential property could be accompanied by multiple benefits of which not all are included in the assessment tool. Further research could suggest examining how other impacts such as indoor environmental quality and employees' productivity, increased asset value and corporate image can be translated into measurable variables.

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