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MASTER

Postponement pays!

the real option theory applied to determine the optimal investment timing of energy saving measures available to newly-build dwellings

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The real option theory applied to determine the optimal investment timing of energy saving measures available to newly-build dwellings.

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Master of Science
in Operations Management and Logistics

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Abstract

Energy saving measures in the residential sector play an important role in the reduction of the primary energy consumption. Such measures may become unprofitable when the energy prices drop after the upfront investment costs of the measure are incurred. This research examines the effect of future energy prices uncertainty on the optimal investment timing and the value of options on energy saving measures embedded in newly-build dwellings. A binomial option pricing model based on standard option theory is tailored to the specific context. The results show that at the current level of energy prices, options on energy saving measures carry along a significant value of waiting. This means that although it may be profitable to take these measures today, it is even more profitable to postpone these measures and wait until the energy prices have risen sufficiently. Furthermore, the results show that the total value of options on energy saving measures embedded in an energy concept reduces the expected total cost of ownership of the energy concept significantly. Overall, the results show that from an economic perspective, a future-prepared energy concept is more valuable than an energy efficient concept.

Preface

This document reports on my thesis project which concludes my master program Operations Management and Logistics of the Eindhoven University of Technology. I started this program after I obtained my master degree in Architecture, Building and Planning, motivated by personal interest in business processes. Because I followed the program for the greater part parallel to my full-time employment as a structural engineer, I welcome the free weekends and vacations in the near future. This does not mean that I did not accomplish the program with much interest, pleasure and enthusiasm.

My thesis project involved a study to the optimal timing of energy saving investments in the residential sector. The subject of energy conservation received increased interest recent years and development of real estate linked with my existing knowledge and experience. The study was executed at Bouwfonds Property Development which is a member of Rabo Real Estate Group. Bouwfonds is active in development of residential real estate nationally as well as internationally for more than 65 years. By executing the study at Bouwfonds, I was able to supplement the study with much context specific data which made the study interesting and practically relevant.

I would like to acknowledge the people who supported me in completing this master program successfully. First I would like to thank my primary supervisors Mr. Reindorp from the Eindhoven University and Mr. Van de Griendt from Bouwfonds for being supportive in content and process during the thesis project. Your suggestions and comments led to substantial improvements in this thesis project. Furthermore, I would like to thank Mr. Van de Griendt and his colleagues for providing me the opportunity to execute my thesis project at Bouwfonds. And last but not least, I would like to thank my parents Jo and Attie and my girlfriend Janske for being patient, encouraging and mentally supportive during the whole master program, especially Janske who was also deprived of a decent holiday last summer.

Nijmegen, November 2011 Koen van Cann

Summary

Dutch households account for 13 percent of the total Dutch primary energy consumption. The large disadvantages of primary energy consumption have lead to numerous covenants to reduce the energy consumption of buildings such as the *Energy Performance Building Directive* and the *Lente Akkoord* and to development of numerous energy-efficient techniques to apply in buildings. However, the only lawful instrument of the Dutch government to enforce energy conservation in buildings is the energy performance coefficient (EPC) of new buildings.

Capital investments may be hindered by market obstacles such as inadequate information of investors. This research examines the option-to-wait effect on the optimal investment timing. If an irreversible investment with uncertain future revenues yields a small expected return today, it may be optimal to postpone the investment and wait for more profitable circumstances to avoid the possibility of a negative realization on an *ex post* basis. Energy saving measures to dwellings are irreversible due to the large unrecoverable upfront investment costs and have uncertain future revenues due to the uncertain evolution of energy prices over time.

The main research objective was to determine the optimal investment timing and option value of energy saving measures available to newly-build dwellings. The research findings may help property developers and homeowners to optimize their capital investments and may substantiate the relation between the energy efficiency and market prices of dwellings.

Energy saving measures are considered as an upgrade of an element of an energy concept in a dwelling from a reference level to an energy efficient level. The reference level of energy concepts was defined by the current building codes. The main energy saving measures available to newly-build dwellings that may be postponed to the exploitation phase of the dwelling are a PV-system, heat pump and solar water heater.

A technical model was developed to determine the energy consumption of dwellings and the potential energy savings due to the energy saving measures. In the model is the dwelling-related energy consumption determined analogous to the EPC method of NEN 5128 and the user-related energy consumption based on an average Dutch household.

An economic model was developed to determine the option values of energy saving measures and the contribution of these option values to the value of the reference energy concept. The economic model comprises two submodels. The first submodel is a binomial option pricing model and was used to determine the option values of the measures. The binomial model was constructed in a discrete-time framework with a finite time horizon. The stochastic energy price evolution is modelled with a multiplicative binomial process with characteristics based on historical data. The present value of an option is obtained with contingent claims analysis which assumes that the risks associated with holding an option may be hedged with the use of other traded assets.

The second submodel is a conventional net present value model and was used to determine the total cost of ownership of the initial energy concept installed into the dwelling at the outset. The option values and total cost of ownership compile the expected total cost of ownership of an energy concept which is representative for the value of an energy concept.

The option values of the PV-system, heat pump and solar water heater are between 1.200 and 5.400 euro. This means that the opportunity to take these energy saving measures in the future is indeed valuable. The option value of a measure consists of the net present value of the measure if taken today and the value of waiting.

The net present values of the PV-system and heat pump are positive and hence it is profitable to take these measures today. The net present value of the solar water heater is negative and hence it is unprofitable to take this measure today.

The options on the PV-system, heat pump and solar water heater carry along a value of waiting of between 2.000 and 4.100 euro. The value of waiting originates from the probability that these measures, if taken today, become unprofitable when the energy prices drop after the investment costs are incurred and should not have been taken on an *ex post* basis. Waiting until the energy prices have risen sufficiently and this scenario is negligible, generates value. This means that although it may be profitable to take these measures today, it is even more profitable to postpone these measures and wait until the energy prices have risen sufficiently.

The total option value of the considered measures reduces the expected total cost of ownership of the reference energy concept with 12 percent. This means that the flexibility embedded in the reference energy concept to incorporate (additional) energy saving measures in the future contributes significantly to the value of this energy concept.

The main managerial implication of these model results is that a future-prepared energy concept is more valuable than an energy efficient concept because the expected total cost of ownership of a future-prepared concept is smaller. The economic disadvantage of the energy efficient concept is that the additional investment costs may not be recouped by the associated energy costs savings when the energy prices drop after the investment is made. The economic advantage of the future-prepared concept is that it has the flexibility to incorporate energy saving measures when the energy prices rise and to postpone these measures when the energy prices drop. And because the upfront investment costs of a future-prepared concept are smaller, this concept is also more viable in the current economic climate in which consumers are reluctant to make large capital investments.

When the energy efficiency of a newly-build dwelling is required to improve beyond the reference level, the value of waiting forgone by exercising one or more options should be compensated by one of the involved parties in order to maintain the economic viability of the property development project. A property developer may compensate via for example economics of scale or technological development. A homeowner may compensate via appreciation of the soft benefits of an energy efficient concept. And a local government may compensate via for example a subsidy, tax discount or reduction in the land price.

Finally, when the energy efficiency of a newly-build dwelling is required to improve, it is optimal to exercise the option on a PV-system or heat pump before a solar water heater because in that case minimal value of waiting is forgone. If for example the EPC of a dwelling is required to decrease with 0,10, exercising the option on a heat pump or PV-system nullifies a value of waiting of approximately 1.100 euro while exercising the option on a solar water heater nullifies a value of waiting of 2.200 euro.

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1 Introduction

1.1 Energy consumption and dwellings

Despite of the renewed interest in energy conservation recent years increased the total Dutch energy consumption with over 6 percent in the period 2000 to 2009. The main energy sources are fossil fuels such as natural gas, petroleum and coal. Unfortunately, the contribution of renewable energy sources is still only 4 percent. Dutch households account for approximately 13 percent of the total energy consumption[1]. The main energy sources of households are natural gas and electricity (www.compendiumvoordeleefomgeving.nl, 10-10-2011).

The large primary energy consumption causes a national and international recognized problem. Primary energy is energy derived from fossil fuels like natural gas, petroleum and coal. Large disadvantages of consumption of fossil fuels are: the supply of fossil fuels is finite, the combustion of fossil fuels causes greenhouse gasses and acidifying gasses and the supplying regions are often politically unstable. These disadvantages have lead to numerous initiatives to reduce the primary energy consumption and associated deleterious emissions. Some known examples are:

- The Kyoto protocol (1997). The objective of this worldwide protocol between industrialised countries is to reduce the emissions of greenhouse gasses. Associated countries agreed to reduce these emissions in the period 2008 to 2012 on average with 5 percent with respect to the level of 1990[2].
- The Energy Performance Building Directive (2003). The objective of this directive is to improve the energy performance of buildings in the European Union. Member states are obligated to institute a general methodology to determine the energy performance of buildings, minimal requirements regarding the energy performance of new buildings and the certification of existing buildings (i.e. the energy label).
- Het Lente Akkoord (2008). The objective of this Dutch convention between the national government and property developing market parties is to realize more energy efficient buildings[3]. It is agreed to construct newly-build dwellings 50 percent more energy efficient in 2015 with respect to the level of 2007. Furthermore is agreed to construct newly-build dwellings energy neutral in 2020[4]. These objectives have to be realized with the development of energy efficient techniques and concepts, application of proven techniques on a large scale, sharing and distribution of knowledge and experiences, and improvement of methods to measure the energy consumption.

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[1] This percentage excludes transportation of households. The energy consumption of households was constant in the period 2000 to 2009 in spite of an increase of the number of households and an increase of energy consumption per household due to warm tap water and electricity. These increases were namely compensated by a large decrease of the energy consumption per household due to space heating. This decrease was caused by the invigorated building codes and improved heating techniques (AgentschapNL, 2010a).

[2] The Dutch government agreed to reduce the emission of greenhouse gasses in the period 2008 to 2012 with 6 percent.

[3] The Dutch government is represented by WWI and VROM. The property developing market parties are represented by Bouwend Nederland, Aedes, NEPROM en NVB.

[4] The ambition for 2011 to construct newly-build dwellings 25 percent more energy efficient with respect to the level of 2007, is already secured in the Dutch building codes.

The only lawful instrument of the Dutch government to enforce energy conservation in buildings is the energy performance coefficient (EPC) of new buildings. The EPC indicates the energy efficiency of a building and the building codes prescribe a maximum limit to the EPC of new buildings. This limit is established in 1996, has gradually invigorated since then and is expected to invigorate even further in 2015. The current limit is 0,60 for dwellings.

The energy consumption of an average Dutch household is 1540 m^3 natural gas and 3480 kWh electricity (www.Nibud.nl, 23-05-2011). This consumption is due to space heating, space cooling, ventilation, warm tap water, lighting, cocking and electric appliances. The main determinants of the energy consumption of a household are the size and thermal shell quality of the dwelling, the building installations and the size and behaviour of the household itself. For example, an existing dwelling with a moderate thermal shell quality consumes on average 1150 m^3 natural gas due to space heating while a newly-build dwelling with a high thermal shell quality consumes on average 400 m^3 natural gas (Van Eck, 2010). And for example, a single-person household consumes on average 1980 kWh electricity while a couple with children consumes on average 4270 kWh electricity (De Vries, 2010). Figure 1 shows the annual energy bill of an average Dutch household.

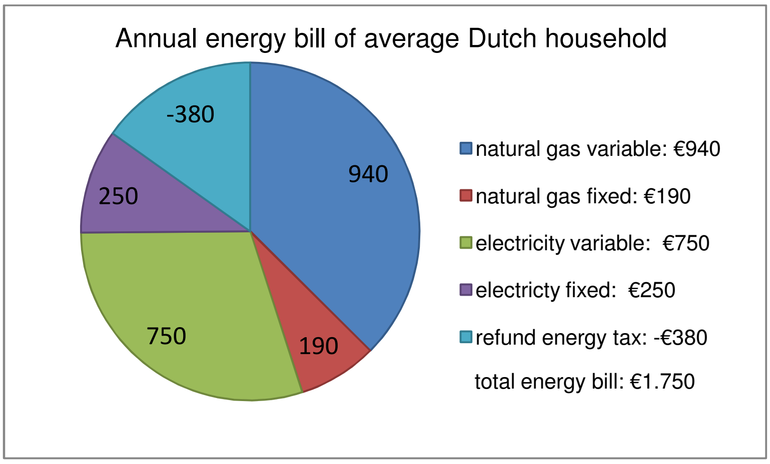

Figure 1: annual energy bill of average Dutch household (www.energieprijzen.nl, 01-07-2011) and (www.Nibud.nl, 23-05-2011).

The energy efficiency of a dwelling is a parameter under control of the homeowner or property developer and several studies show that there are many cost-effective energy-efficient improvements available to dwellings. For example, the natural gas consumption of existing dwellings may be reduced by 35 percent with measures that have a payback period less than 15 years. The greatest part of these energy savings is realizable by application of cavity wall insulation and roof insulation at aged private detached and semi-detached dwellings. These measures have a payback period less than 5 years (Ecofys, 2005). And for example, the total living expenses of a very energy efficient newly-build dwelling are lower than of a conventional newly-build dwelling (AgentschapNL, 2010b)[5]. The total living expenses comprise the energy costs and mortgage costs. It is assumed that the additional investment costs of the very energy efficient dwelling may be financed within the mortgage.

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[5] See also the presentation “Waarom aannemers in de woningbouw passiefhuizen bouwen – financieringskosten en energiekosten” by P. Hameetman (www.saxion.nl, 17-10-2011).

Social pressures to reduce primary energy consumption and the invigorated building codes have lead to the development of new energy concepts in dwellings. An energy concept is a coherent combination of architectural, constructional and installation techniques applied in a dwelling that lead to a required energy performance (AgentschapNL, 2010b). Energy concepts may apply different techniques to obtain an identical energy performance. Two examples of energy concepts are:

- In a passive dwelling is the thermal comfort achieved solely by post-heating or post-cooling of the ventilation air without a need for a conventional heating system. Passive dwellings typically include passive solar gain and a shell with extremely low air-permeability and high heat-resistance. The maximum annual energy consumption due to space heating of a passive dwelling is 15 kWh/m² (www.cepheus.de, 12-10-2011).
- A future-prepared dwelling is structurally and technically prepared to incorporate additional energy saving measures today or in the future. With these measures, it is possible to improve the energy efficiency of the dwelling incrementally until the EPC is zero. An example of the future-prepared energy concept is the climate ready concept, see Figure 2.

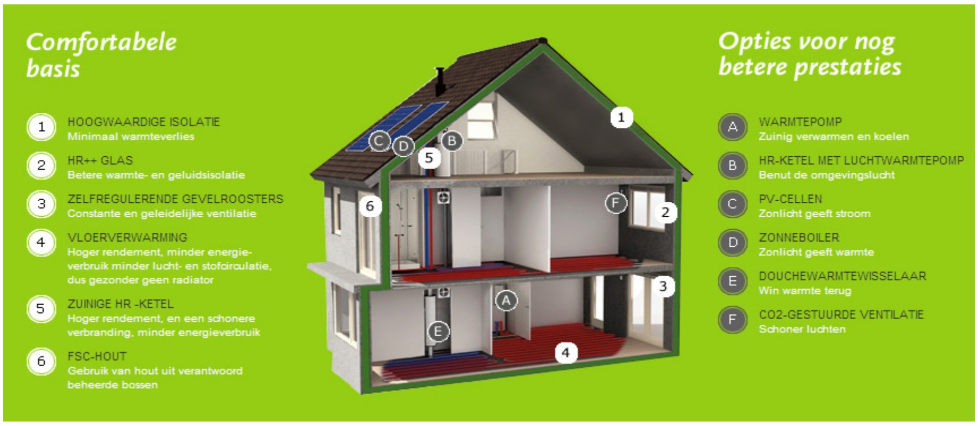

Figure 2: example of future-prepared energy concept (www.climateready.nl, 19-04-2011).

The reference level with regard to the energy efficiency of dwellings is defined by the current building codes. So by definition, energy efficient dwellings have a lower EPC than the maximum limit prescribed by the current building codes. Typically, energy efficient dwellings require additional upfront investment costs. The main advantages of energy efficient dwellings are a lower energy bill, less detriment to the environment and a comfortable and healthy internal climate (when floor heating applied).

What kind of energy concept to apply in a newly-build dwelling is often a complex decision because many aspects play an important role. Moreover, the significance of each aspect may depend on specific project circumstances. For example, a commitment to a certain energy concept can result from the corporation with the local government in an area development project. Or certain energy concepts are excluded because they worsen the saleability of a dwelling or the additional investment costs may not be recharged to the customers because of the consumers' constrained finance opportunities or because of the current pressure on the market prices of newly-build dwellings.

1.2 Research proposal

1.2.1 Problem statement

In the previous section is discussed that the residential sector accounts for a substantial part of the primary energy consumption. Furthermore, many apparently cost-effective energy-efficiency improvements are available to existing dwellings as well as to newly-build dwellings. Besides the financial advantages to the homeowners, these energy efficiency improvements are also desirable from a social perspective to secure the supply of energy and mitigate the global climate change. However, the full advantage of energy efficiency potentials is hindered by the presence of obstacles in the market, often referred to as market barriers (IEA, 2008).

Several studies have analyzed these barriers and have asserted an "energy efficiency gap" between the current energy consumption and the optimal energy consumption from a social perspective. For example, Jaffe et al. (2004) discus the market barriers and market failures that can lead to underinvestment in cost-effective energy-saving technologies. These market imperfections are:

- Inadequate information: for example a builder may not be able to recover the costs of an energy saving investment if the purchaser has incomplete information about the magnitude of the resulting energy savings.
- Environmental externalities: consumers of fossil fuels face no economic incentive to minimize the costs of pollution associated with the combustion of fossil fuels.
- Innovation externalities: innovators and manufacturers face no economic incentive to maximize the knowledge spillovers to others.
- Inadequate energy prices: consumers face an inadequate incentive to conserve energy because the marginal cost of energy differs from the marginal social cost.
- The option-to-wait effect: irreversibility and uncertainty about the future benefits tend to raise the required hurdle rate and delay investments in energy saving technologies.
- Unaccounted costs and biased energy savings: simple cost-effectiveness calculations typically overlook some adoption costs or overestimate the expected energy savings.
- Heterogeneity in characteristics of adopters: even if a given technology is cost-effective on average, it will most likely not be for all adopters.

This research studies the option-to-wait effect on the adoption of energy saving technologies in the residential sector in more detail. The tendency to delay irreversible investments with uncertain future revenues originates from the value of waiting. The basic insight is that if the expected return on an investment today is small, the investors should postpone the investment in some optimal way to avoid the bad realization when (energy) prices fall and the investment becomes unprofitable on an *ex post* basis (Hasset and Metcalf, 1993)[6]. The opportunity to postpone an irreversible real investment with uncertain future revenues is called a real call option. The real option theory addresses the optimization problem of the investor deciding how long to wait before exercising the real call option (i.e. making the investment).

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[6] Postponing the investment may also be valuable in the absence of uncertainty. Both the growth as well as the uncertainty associated with the value of the asset can create a value of waiting an thereby affect investment timing (Dixit and Pindyck, 1994).

Numerous studies examined real option effects in the residential sector. For example, Grenadier (1996) used strategic option exercise games to provide a rational explanation for development cascades and overbuilding in real estate markets and Eichholtz et al. (2011) analyzed the effect of the option to rebuild existing dwellings on the dynamics of house prices. Moreover, several studies examined real option effects on energy saving investments in the residential sector. For example, Hassett and Metcalf (1993) developed a simple economic model to rationalize the apparently high discount rates attributed to consumers making energy conservation investments, Van der Maaten (2010) analyzes whether a Dutch subsidy program properly compensates investors for the real option value forgone by investing in a solar hot water system and Diederen et al. (2003) explain the gap between the predicted and observed level of adoption of energy saving technologies in the Dutch horticulture sector by using a real options framework. This research is aimed at extending the body of existing knowledge of real option effects on energy saving investments in the residential sector from the single product level to the aggregate dwelling level.

The revenues of energy saving investments depend on the future energy savings resulting from the investment and by the future energy prices. This research addresses the uncertainty relating to the future energy prices[7]. Figure 3 depicts the natural gas price to Dutch homeowners in the period 1997 till 2010. It can be observed from the figure that the trend and volatility of the natural gas price were relatively high in this period[8]. As a consequence of the trend, energy saving investments probably become more profitable in the future and homeowners are expected to make more energy saving investments in the future. However, as a consequence of the volatility, these homeowners are also expected to postpone these investments until the return on the investment is large enough to assure that the investment may not become unprofitable on an *ex post* basis.

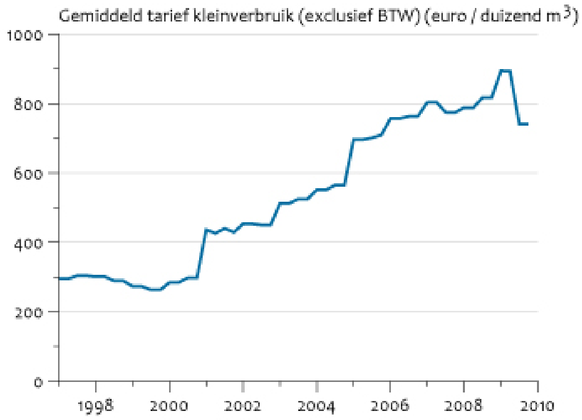

Figure 3: natural gas price to Dutch homeowners (www.cbs.nl, 05-05-2011).

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[7] Uncertainty may also relate to the future energy savings resulting from the investment. For example, the actual energy savings depend on the project-specific characteristics and become known only after the investment is made. However, it is assumed that the uncertainty relating to the future energy savings is small when compared to the future energy prices and hence this source of uncertainty is not addressed in this research.

[8] The average annual growth rate of the natural gas price approximated 9 percent which is considered high when compared to the general consumer price index of approximately 2 percent. Furthermore, the natural gas price dropped significantly twice in 13 years which is considered volatile. The trend and volatility of the electricity price were somewhat smaller.

1.2.2 Objective

The research objective is to determine the effect of energy prices uncertainty on the optimal investment timing and option value of energy saving measures available to newly-build dwellings and to determine the effect of these option values on the value of energy concepts.

The relevance of this research is twofold:

- Practical usefulness: the results may optimize the capital investments of property developers and property owners with regard to the energy efficiency of dwellings. These parties are confronted with an assortment of energy saving measures available to existing and newly-build dwellings. This research provides an economic framework, in addition to existing technical, commercial and social frameworks, to assess the marginal economic value of energy saving investments.
- Scientific contribution: the results may substantiate the relation between the energy efficiency and market prices of dwellings. Brounen and Kok (2010) found statistical evidence on a positive relation between the energy label of a dwelling, which may be considered as an aggregate measure for the energy efficiency of the dwelling, and the market price of the dwelling. However, the price premium found for energy efficient dwellings reflects more than just future energy savings alone. This research examines whether the option to improve the energy efficiency of a dwelling and alter the future energy costs, represents a substantial value.

The main research questions are:

- What are the main energy saving measures available to newly-build dwellings that may be postponed to the exploitation phase of the dwelling? These measures improve the energy efficiency of a dwelling from a reference level to an energy efficient level.
- What are the option values of these energy saving measures when energy prices uncertainty is taken into account? This research takes a pure economic perspective on option values of these energy saving measures. So commercial, technical or social aspects are not considered in the option value.
- What are the optimal investment timings of these energy saving measures when energy prices uncertainty is taken into account? Or in other words, is it economically optimal to make a newly-build dwelling today more energy efficient than required by the current building codes? And how is the energy efficiency of the dwelling most economically improved if external conditions require so?
- To what extent contribute the option values of these energy saving measures to the value of an energy concept?

1.2.3 Scope

The research scope is constrained to:

- newly-build dwellings (and no existing dwellings or commercial buildings),
- individual energy concepts (and no collective energy concepts),
- energy prices uncertainty (and all model parameters are assumed deterministic),
- energy saving measures under control of a property developer and
- proven techniques (which are actually considered for application).

In this research are subsidies on energy saving investments not addressed.

The value of energy concepts is in this research defined as the net value of the discounted expected future benefits and costs of the energy concept. So future transactions of dwellings may impact the value of energy concepts via the resale price paid for the energy concept (as part of the dwelling). However, it is assumed that the resale price paid for energy concepts is equal to the value of the energy system at that moment[9]. In this way, the value of energy concepts is independent of any transaction of the dwelling in the future.

The transactions of dwellings from a property developer to the first homeowner cause a split incentives problem. The investment costs of an energy concept are borne by the property developer while the operating benefits and costs are borne by the homeowners. This separation of costs ownership causes the split incentives problem and hinders an optimization of total costs of ownership. This aspect is not addressed in this research.

1.2.4 Outline report

Figure 4 shows the structure of the main parts of this research (including heading numbers). Chapter two starts with a review of the real option theory. This theory is applied in the economic model later on. In chapter three is a technical model developed to determine the energy consumption of energy concepts and the potential energy savings due to energy saving measures. Chapter three also discusses the technical model inputs. The technical model results are presented in chapter six together with the economic model results. Notice that the technical model results serve as inputs to the economic model. In chapter four is an economic model developed to determine the option values of energy saving measures and the total cost of ownership of initial energy concepts. The sum of these two results is considered representative of the value of energy concepts. Chapter five discusses the economic model inputs. Chapter six presents the model results and includes a sensitivity analysis. The main economic model results are the option values of energy saving measures embedded in the reference energy concept and the total cost of ownership of the initial reference energy concept. Chapter seven discusses the results of two surveys amongst homeowners. These surveys are used to find out to what extent the economic model fits the actual behaviour and preferences of homeowners. Finally, chapter eight concludes this report and presents the model results, managerial implications and generalizability of the results.

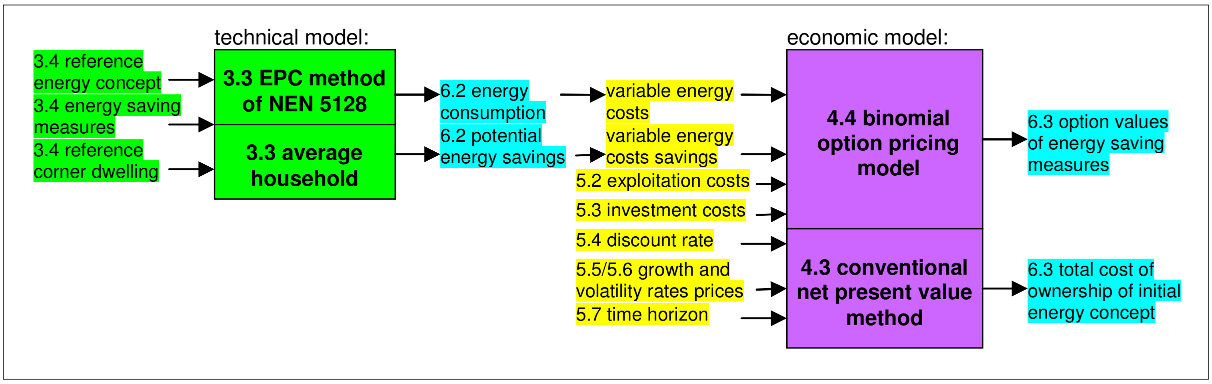

Figure 4: outline of main research parts.

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[9] There are several reasons why the proposed equality may not hold: bounded rationality of parties, transaction costs, demand and supply ratio, limited capital resources of consumers etc. On the other hand, the proposition that the market price paid for an object is equal to the value of the object is at least intuitively sound.

2 Real option theory

2.1 Introduction

The central notion in this research is an option. An option is the right, but not the obligation, to acquire an asset now or in the future[10]. Usually, acquisition of the asset is irreversible and the acquisition costs are deterministic while the revenues of the asset evolve stochastically over time. In contrast to financial options, real options involve tangible assets (e.g. buildings or facilities) instead of financial assets (e.g. shares or bonds). Section 2.2 discusses financial option models because the real option theory originates from the financial option theory.

The real option theory is often cited as superior to the conventional net present value method. Within the net present value method, the value of an investment project is equal to the sum of the projects' discounted cash flows. A project is profitable and accepted if this net present value is equal or larger than zero, and rejected otherwise. In effect, the real options theory adds another criterion to the investment decision: the project is postponed when it is more profitable to wait until the circumstances to invest are more favourable. Section 2.3 discusses real option models to give an overview of what kind of models are available to solve real investment problems.

Section 2.4 discusses four studies which applied real option models to investment problems in the real estate sector and which provide empirical evidence of managers including real option value in their investment decisions. Finally, section 2.5 concludes this chapter.

2.2 Financial option models

2.2.1 The Black and Scholes model

Black and Scholes (1973) were the first to derive a complete valuation formula for a financial call option. They derived the value of a call option on a stock by using the principle that options are priced such that sure profits are not possible (no-arbitrage condition). A hedged position is created by going long in a stock and short in a number of options on the stock[11]. Because the future value of the hedged position will not depend on the future price of the stock, the return on the hedged position is riskless. So the current value of the hedged position (and with that the current value of the option) is determined with the risk-free rate of return. In their model is assumed that the stock pays no dividend, the stock price follows a geometric Brownian motion[12] and the option may be exercised only on the expiration date. Their main result is the call option valuation formula, see the next page. The parameters d_1 and d_2 in the formula depend on the volatility of the stock price, time to maturity, current stock price, exercise price and risk-free rate of return. Notice that the expected return on the stock does not appear in the formula. Because the model is solved using stochastic calculus, it is not efficient to address extensions to the general call option pricing problem such as financial options that may be exercised early or real options with more complex structures.

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[10] At a fundamental level, there are two types of options. A call option gives the holder the right, but not the obligation, to acquire the asset. A put option gives the holder the right, but not the obligation, to sell the asset.

[11] The number of options is chosen such that the change in the value of the long position in the stock will be exactly offset by the change in the value of the short position in the options.

[12] A geometric Brownian motion is a continuous stochastic process in which the variable may take only positive values and future values of the variable are log-normally distributed, see for more information appendix A.

$$C = S * N(d_1) - K * e^{-r_f(t^*-t)} * N(d_2)$$

with: C : current value of call option
S : current stock price
t : current time
t* : maturity date of call option
K : exercise price
r_f : risk-free rate of return
N(d) : cumulative normal density function

From the formula above can be observed the three primary sources of call option value. The first source is the net present value of the option which reflects the value to an investor who exercises immediately (S-K). The second source is the time value which reflects the probability that if an option is out-of-the-money now, it is in-the-money at expiration ($e^{(-rf(t^*-t)}$). The third source is the volatility value which reflects the fact that greater volatility of the stock price increases the upside potential gain, but has no effect on the downside loss which is limited to the cost of the call option ($N(d_1) - N(d_2)$). The time value and volatility value are strongly related and both decrease to zero when the maturity date is approached.

Figure 5 shows the call option value as a function of the current stock price as well as the two boundaries to the option value. The option value is always less than the stock price but always greater than the intrinsic value of the option (i.e. the maximum of zero and the stock price minus the exercise price). If the time until maturity decreases, the option value moves from the upper boundary to the lower boundary.

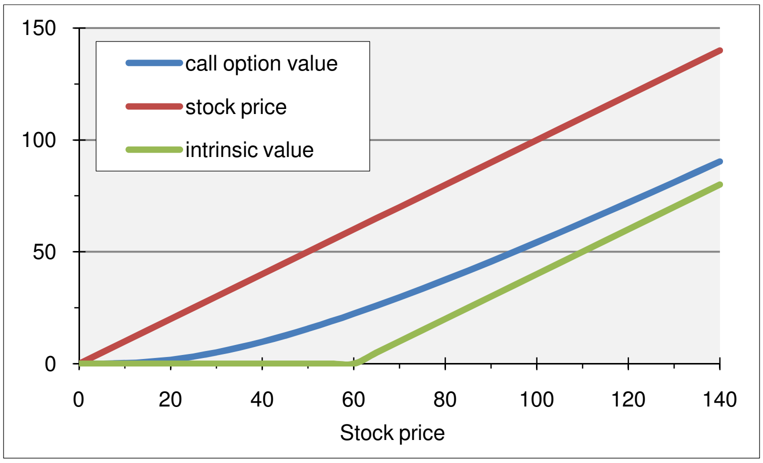

Figure 5: value of financial call option.

2.2.2 The Cox, Ross and Rubinstein model

Cox, Ross and Rubinstein (1979) presented an alternative call option valuation formula also known as the binomial option pricing formula. In contrast to the Black and Scholes model which is constructed in a continuous-time framework is this model constructed in a discrete-time framework. The fundamental feature of the binomial model is that the stock price follows a multiplicative binomial process over discrete periods. In each period, the stock price goes up wit rate u and probability p or goes down with rate d and probability (1-p), see Figure 6 on the next page. The up and down rates depend on the volatility of the stock price and the probabilities depend on the expected return on the stock. This binomial process yields an event tree. The binomial model is solved by calculating first the option values at the final nodes (maturity date) and then working backwards through the event tree towards the first node (valuation date). As in the Black and Scholes model, this model uses the no-arbitrage condition to derive the option value[13].

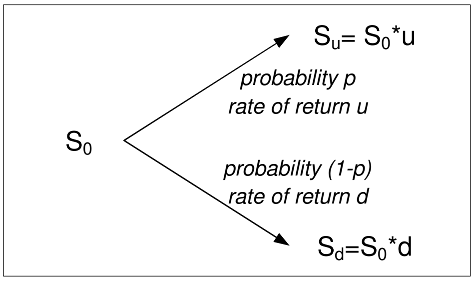

Figure 6: multiplicative binomial process of stock price.

The one-period binomial option pricing formula is presented below. This formula is easily extended to many more periods. Notice that the option value is independent of the actual probability that the stock price will rise or fall. Instead of these objective probabilities, the formula involves the risk-neutral equivalent of these probabilities q and (1-q). So the option value can be interpreted as the expected discounted future payoff in a risk-neutral world. Because this model is solved using only elementary mathematics, it is efficient to address extensions to the general call option pricing problem.

$$C = \frac{(qC_u + (1-q)C_d)}{(1+r_f)} \nless S - K$$

$$q = \frac{(1+r_f) - d}{u - d} \text{ and } 1 - q = \frac{u - (1+r_f)}{u - d}$$

with: C : current value of call option
C_u : call option value after upward move $C_u = \max[0; S_u\text{-}K]$
C_u : call option value after downward move $C_d = \max[0; S_d\text{-}K]$
S : current stock price
K : exercise price
r_f : risk-free rate of return

The discrete binomial option pricing formula converges to the continuous Black and Scholes call option valuation formula when the number of time intervals goes to infinity, if the multiplicative binomial process of the stock price converges to a geometric Brownian motion. This is the case if the associated parameters are chosen in the following way: $u = \exp(\sigma\sqrt{\Delta t})$, $d = \exp(-\sigma\sqrt{\Delta t})$ and $p = ½*(1 + (\alpha/\sigma)\sqrt{\Delta t})$.

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[13] A replicating portfolio is compiled, existing of a number of shares and a short position in riskless bonds. When the number of shares and bonds are chosen in the right proportion, this portfolio replicates the future return on a call option. As a consequence, the current value of the call option is equal to the (known) current value of the replicating portfolio.

2.3 Real option models

2.3.1 Overview model types

On basis of the time framework and solution procedure are four model types discerned to solve real option problems, see Table 1. The Black and Scholes model and Cox Ross and Rubinstein model discussed in the previous section use both contingent claims analysis in respectively a continuous-time and discrete-time framework. The two models elaborated in this section use both dynamic programming in respectively a discrete-time and continuous-time framework. The difference between contingent claims analysis and dynamic programming is discussed below.

Table 1: real option model types.

time framework	solution procedure	
	contingent claims analysis (risk-free rate of return)	dynamic programming (risk-adjusted discount rate)
discrete-time (binomial model)	section 2.2.2 (CRR)	section 2.3.2 (D&P)
continuous-time (differential equation)	section 2.2.1 (B&S)	section 2.3.3 (D&P)

Two solution procedures (i.e. mathematical techniques) to solve real option problems are: dynamic programming and contingent claims analysis (Dixit & Pindyck, 1994). Dynamic programming is a very general tool for dynamic optimization. The essential idea of dynamic programming is to split a sequence of decisions into two parts: the immediate decision, and the remaining decisions, all of whose effects are summarized in the continuation value. The idea behind this decomposition is formally stated in Bellman's Principle of Optimality and the result of this decomposition is called the Bellman equation. Appendix B contains the general Bellman equation in continuous-time which is an equilibrium condition with on the right-hand side the expected total return per unit time from holding an asset and on the left-hand side the return per unit time that an investor would require for holding the asset. The required return is based on an exogenous risk-adjusted discount rate. In a continuous-time framework, the Bellman equation may be first reworked to a differential equation and then solved with the use of economic boundary conditions (see section 2.3.3).

Contingent claims analysis builds on ideas from financial economics. The essential idea of contingent claim analysis is to replicate the return and risk characteristics of an option through a portfolio of traded assets. The value of the option must equal the market value of this replicating portfolio because any discrepancy would be exploited by arbitrageurs who look for sure profits (no-arbitrage condition). For the replicating portfolio, it is sufficient to find some traded assets whose stochastic fluctuations are perfectly correlated to the option.

In a continuous-time framework, dynamic programming and contingent claims analysis yield very similar differential equations. The difference is that the differential equation derived with contingent claims analysis incorporates the risk-free rate of return instead of the exogenous risk-adjusted discount rate and the risk-free rate of return minus the convenience yield instead of the growth parameter of the underlying asset. This means that future risky cash flows can be valued by discounting it at the risk-free rate of return, provided that the growth parameter of the cash flows is replaced by the risk-free rate of return minus the convenience yield[14].

All model types yield in principle the same result[15]. However, the main advantage of a discrete-time framework is the use of only elementary mathematics which makes it efficient to assess real options with more complex structures. And the main advantage of contingent claims analysis is that it treats the risks associated with an option more consistent when these risks may be mimicked with traded assets (Dixit and Pindyck, 1994).

2.3.2 Discrete-time model of basic investment problem

The basic investment problem in this chapter concerns a firm which has the opportunity but not the obligation, to make an irreversible investment to be able to produce a good. Producing the goods yields a profit flow. The profit level and hence the present value of future profits evolve stochastically over time according to a geometric Brownian motion. The investment can be made once and the required capital investment is constant in time. The firm's investment problem is to determine the optimal investment timing. Table 2 summarizes the problem parameters.

Table 2: problem parameters of basic investment problem.

abbreviation	model parameter
I	required capital investment
V	present value of future profits
F	value of investment opportunity
ρ	exogenous (risk-adjusted) discount rate
t	time

This section addresses the basic investment problem with a discrete-time model with only two periods based on Dixit and Pindyck (1994). It is assumed that the present value of future profits in the second period can increase or decrease with respect to the first period, but after the second period, the present value of future profits will remain at this new level forever. Moreover, the firm can make the investment only in the first or second period. These assumptions are relaxed in a continuous-time model in the next section. Further, the optimal investment timing and value of the investment opportunity are determined with dynamic programming.

Consider an example with parameters $I = 1000$ and $\rho = 10$ percent. The time interval between both periods is one year. Furthermore, the present value of future profits increases to 122 percent or decreases to 82 percent in the second year with equal probability. The complete solution to the investment problem consists of three regions:

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[14] The convenience yield is the difference between the expected rate of return on an asset demanded by the market and the expected capital gain on the asset. The convenience yield may come directly (e.g. dividend payments or profit flow) or indirectly (e.g. benefits from holding stock) (Dixit and Pindyck, 1994).

[15] See Cox et al. (1979) for the equivalence of discrete- and continuous-time models. See McDonald (2006) for the equivalence of contingent claims and dynamic programming.

- When it is never profitable to invest in the second year, it is also not profitable to invest the first year and hence $F_0 = 0$.
- When it is profitable to invest only when the present value of future profits goes up in the second year, $F_0 = 0{,}555 * V_0 - 455$[16].
- When it is always profitable to invest in the second year, it is also profitable to invest in the first year and hence $F_0 = V_0 - 1000$.

Figure 7 shows the value of the investment opportunity as well as the net present value of the investment (if made in the first year) as a function of the present value of future profits in the first year. According to the conventional net present value rule, the optimal decision would be to invest in the first year when the net present value is positive (i.e. $V_0 > 1000$) and never invest otherwise. However, the figure shows that when the net present value is small (i.e. $V_0 < 1225$), the value of the opportunity to invest in the second period is larger than the net present value and hence it is optimal to postpone the investment and wait until the second period.

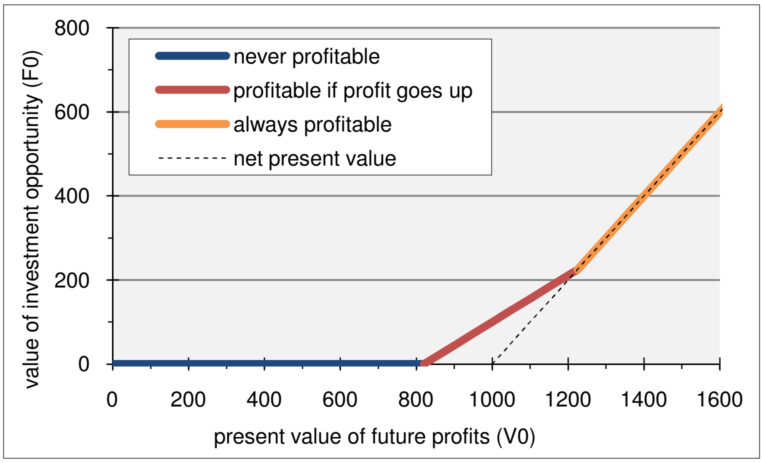

Figure 7: value of investment opportunity according to discrete-time model.

This example shows the surplus value of the real option theory with respect to the net present value method: the investment opportunity is not only assessed on a now-or-never basis, but that the opportunity to wait for (even) more profitable circumstances is also assessed. The decision rule according to the net present value method works well when the net present value is very positive or very negative but yields inferior decisions when the net present value is around zero. In that latter case, the optimal decision is to wait because the opportunity to invest later on is more valuable than investing today. The surplus value of the investment opportunity with respect to the net present value of the investment is defined as the value of waiting and originates primarily from the fact that waiting for more profitable circumstances reduces the probability that the investment becomes unprofitable on an *ex post* basis. So in effect, the real option theory adds another opportunity cost of investing to the conventional net present value rule: the present value of future profits should compensate for the required capital investment as well as for the value of the investment opportunity itself. And by definition, the optimal investment threshold is reached when the value of waiting has reached zero.

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[16] When it is profitable to invest only when the present value of future profits goes up in the second year, then is $F_0 = [50\% * (1{,}22 * V_0 - 1000) + 50\% * 0] / 1{,}10 = 0{,}555 * V_0 - 455$.

When the binomial model discussed in this section is extended to more periods, the value of the investment opportunity stays a piecewise-linear function, but now there are more pieces. Because the uncertainty over future profit levels will increases when additional periods are added, the value of the investment opportunity as well as the range in which the best strategy is to wait are increased. As the number of periods becomes very large, the value of the investment opportunity will approach a smooth convex curve that starts at zero and rises to meet the net present value line tangentially at the threshold where immediate investment is optimal. Such a smooth curve is obtained with a continuous-time model in the next section.

2.3.3 A continuous-time model of the basic investment problem

This section addresses the basic investment problem discussed in the previous section with a continuous-time model based on Dixit and Pindyck (1994). The value of the investment opportunity and optimal investment timing are determined with dynamic programming. The procedure is summarized as follows. First is the general Bellman equation reworked to the Bellman equation in the continuation region (i.e. when waiting is optimal). Then is this Bellman equation reworked to a differential equation. And finally is this differential equation as well as the optimal investment threshold solved using three economic boundary conditions. More details of this procedure are presented in appendix B. The resulting optimal investment threshold and the value of the investment opportunity are:

$$V^* = \frac{\beta_1}{\beta_1 - 1} I$$

$$F(V) = \begin{cases} AV^{\beta_1} \text{ for } V < V^* \text{ (wait and invest later)} \\ V - I \text{ for } V > V^* \text{ (invest immediately).} \end{cases}$$

with: V^* = optimal investment threshold
β_1 = solution to fundamental quadratic equation (see appendix B)
A = constant which depends on β_1 (see appendix B)

Consider an example with parameters $I = 1000$ and $\rho = 10$ percent. Furthermore, the growth parameter of the present value of future profits (α) is zero and the volatility parameter (σ) is 20 percent. Figure 8 on the next page shows the value of the investment opportunity value as a function of the present value of future profits. Given these parameters, the present value of future profits at the optimal investment threshold is ample larger than the required capital investment (i.e. $V^* = 1560$). More specific, when the firm decides to invest, the present value of future profits should compensate for the required capital investment as well as for the value of the investment opportunity itself. Hence the optimal investment threshold is reached when the value of waiting has reached zero.

2.3.4 Extensions of basic investment problem

Numerous studies have addressed extensions to the basic investment problem discussed in the previous two sections. In this section are two notable examples of extensions discussed.

Bouis et al. (2009) extended the basic investment problem from a monopoly situation to an oligopoly situation. The model includes three or more potential firms with each firm facing the basic investment problem. In addition, the profit flow of each firm depends on the number of firms that already entered the market. Because of the strategic interaction between the firms, the investment problem is solved backwards in time using a game theory perspective.

The solution to the investment problem includes the optimal investment thresholds and the value functions associated with each firm. The solution points out that all investment thresholds increase with uncertainty and that an exogenous demand shock has the same qualitative effects on the optimal investment timing of the odd firms, while the direction of this effect is opposite for the even firms. This is called the accordion effect. The implication of these results is that when a firm considers entering a particular market, it is important to investigate the level of anticipated competitors. Furthermore, the results show that the first market entry occurs most early if the number of anticipated entrants is small and even. The implication of this result is that increased competition can actually delay investment.

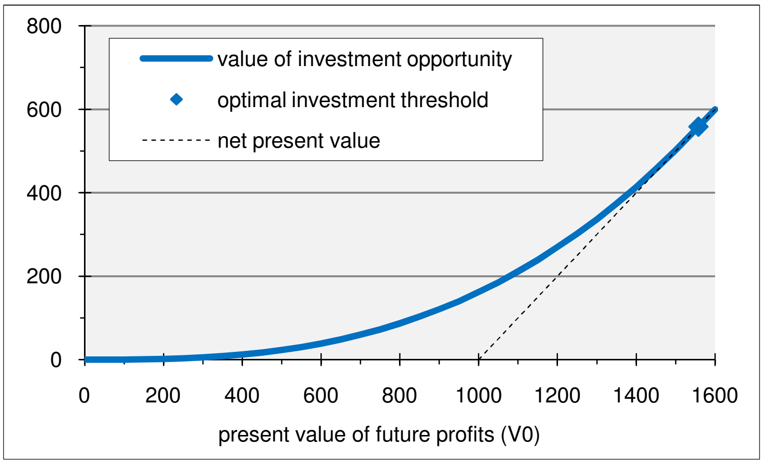

Figure 8: value of investment opportunity according to continuous-time model.

Dobbs (2004) extended the basic investment problem to replacement investment. The model considers a firm that already operates an asset that produces a fixed level of output. The profitability of the firm depends on the level of operating costs which evolve according to a geometric Brownian motion with positive drift because of deterioration of the asset. The firm has the opportunity, but not the obligation, to replace the existing asset with a new identical asset. Associated with this replacement is a capital investment. The firm's investment problem is to minimize the expected discounted total costs, by finding the optimal operating cost level at which the existing asset is replaced by a new asset. The optimal decision to terminate the life of the existing asset should take account of the possibility that the operating costs can go down as well as up. So any flexibility in the replacement decision creates an option value of waiting. The results show that, when uncertainty is introduced, the optimal replacement costs level increases and the total costs decrease. The intuition behind the decrease in total costs is as follows. By increasing the optimal replacement cost level, the decision to replace the asset is made less often, but on the other hand also a better informed decision is made.

2.4 Applied research

This section discusses four studies in which the real option theory is actually applied to real estate investment problems. Furthermore, the results of these studies provide empirical evidence of managers and consumers including real option value in their investment decisions.

The first study (Eichholtz et al., 2011) postulates that market prices of houses are affected by the option to redevelop the existing houses and that the associated option value amplifies the cyclical price swings of existing houses. The redevelopment option is a one-time call option to exchange the current vector of property characteristics for a new (improved) vector of property characteristics at a certain construction cost. In this way, the total house value consists of the use value plus the option value, see Figure 9. When the use value of the existing house is low, the value of the option to redevelop the house is high, and vice versa. It is interesting to note that the redevelopment model includes no underlying stochastic process.

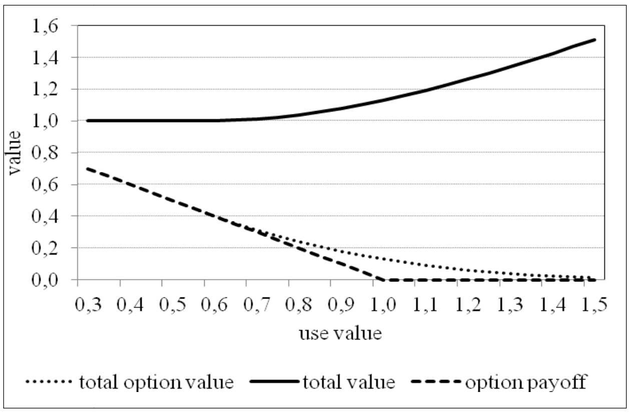

Figure 9: value of existing houses (Eichholtz et al., 2011).

In order to empirically investigate the effect of option value, the development potential is measured by the ratio between the maximum size allowed by zoning and the existing size of the house. The regression equation includes hedonic-, location- and development potential characteristics, and time dummies. The dataset includes all transactions of single-family houses in Berlin from 1978 through 2007. This dataset is unique because it covers the maximum size allowed by zoning as well as the existing size of the house. Furthermore, the time period covers three very different phases of relative tranquillity, boom and bust which are likely to affect the option value.

The regression results show that the estimated elasticity of house value with respect to development potential is significant. The option to add more space to the building is worth up to 98.000 euro for the high option value houses in the boom period. For these high option value houses, about 40 percent of the increase in house value from the quiet to boom period was associated with the change in option value, and about 50 percent of the decline in house value from boom to burst period was associated with the change in option value. For low option value houses, the effects of the redevelopment option are less pronounced but still economically significant.

The main result of the study, that the market price of a dwelling represents the interior space of the dwelling as well as the option to add more space, is relevant to this research. This result is translated to a context of variable energy costs as follows: the market price of a dwelling represents the energy efficiency of the dwelling as well as the option to improve the energy efficiency. Finally, the study is different to this research because the option value is obtained in the absence of uncertainty while this research addresses energy prices uncertainty.

The second study (Grenadier, 1996) investigates the relation between development activity and market conditions for commercial real estate. A real options model is developed which provides potential rational explanations for several real estate phenomena, such as buildings booms. The model considers a local real estate market which consists of two identical buildings, owned by two distinct individuals. Both owners have an opportunity to redevelop their buildings into new superior buildings and earn potentially greater rentals. The redevelopment option is a call option with an exercise price equal to the cost of construction, and the underlying security is a new building. Exercising the redevelopment option influences both building owners. When the first option is exercised, the option exerciser loses current rentals and receives higher monopoly rentals on the new building. The rentals of the existing building drop to a lower level. When also the second option is exercised, both building owners receive duopoly rentals on the new buildings. The stochastic part of the demand function evolves according to a geometric Brownian motion. In the model, total value equals the sum of the value of the existing building plus the value of the option to redevelop.

The results of the study show that, depending on the initial state of demand, redevelopment of the buildings will be sequential or simultaneous. The median time between construction starts is unaffected by changes in the construction time or degree of obsolescence, but is decreasing in demand volatility. This result may provide a rational explanation for rapid successions of exercise strategies (i.e. development cascade). Cities with diversified economies would be less prone to development cascades than cities with significant dependence on a single economic factor. This finding is empirically confirmed by American cities. For example, the Denver and Houston office markets have historically been heavily dependent on the oil industry. In a period of thirty years, over half of all office construction was completed in a four-year interval. The results also show under which conditions, rational value-maximizing developers will simultaneously build in the presence of declining markets, which may provide a rational explanation for recession-induced construction booms. This ‘overbuilding’ is often attributed to some form of irrationality. The probability of such a construction boom is increasing in the construction time and demand volatility. This finding is empirically confirmed by American cities. For example, the Denver and Houston office markets had, during their concentrated burst of office construction, vacancy rates were near 30 percent.

The results of the study are relevant to this research because they build confidence in option value being a relevant aspect in investment decisions of real estate investors. Finally, the study is different to this research because the optimal investment strategy takes into account potential investments of competitors. In this research is competitor behaviour not relevant as it does not affect the investment characteristics (e.g. revenues).

The third study (Diederen et al., 2003) tries to explain the gap between the observed rate of adoption of energy-saving technologies and the predicted rate of adoption by the conventional net present value method. The study considers the adoption rate of gas combustion condensers and heat storage tanks in Dutch horticulture. The study hypothesizes that part of the gap between the expected and observed levels of adoption may be explained by taking into account uncertainty in the future revenues. The net present value is not the optimal criterion to decide on irreversible investments with uncertain revenues because it ignores the option value of waiting for more information. The study uses an investment model based on the real options framework (Dixit & Pindyck, 1994). The model states that, upon investing, the revenues should exceed the initial capital expenditure. The required hurdle rate depends on the parameters of the stochastic process followed by the revenues. In their model, the energy price follows a geometric Brownian motion and the energy tax (policy) follows a Poisson jump process.

The study analyzes data of 491 Dutch firms in 1996 and 1997. For each firm is an estimate of the value of the investment project obtained on basis of firm-specific variables. Because of the absence of firm-specific stochastic variation, all firm values follow the same stochastic process. And as a consequence, the required hurdle rate does not differentiate significantly between adopters and non-adopters. The estimated hurdle rate varies widely across firms and is on average somewhat larger than the required hurdle rate. The difference between the estimated and required hurdle rate does differentiate significantly between adopters and non-adopters. On basis of this variable, the model generates a correct prediction in 70 to 80 percent of the cases which is considerably better than a prediction on basis of the net present value method.

The main result of the study, that adoption of energy saving measures is predicted better by a real option model than a conventional net present value model because the real option model considers the value of waiting for more information, is also relevant in this research. The main differences with this research are that the value of measures is obtained with specific variables of each firm, that future uncertainties relate to energy prices as well as energy tax policies and that only individual measures are examined.

The fourth and final study (Van der Maaten, 2010) reviews a Dutch government subsidy program to stimulate investments in solar hot water systems by homeowners. The study hypotheses that the incentive to invest now in an energy saving measure should compensate for any call option value to defer the investment. The call option value stems from sources of market risks as well as private risks. Furthermore, the study provides a practitioners' model to design policy incentives. The call option value to investment in a solar hot water system was determined with a binomial model. In this model, the underlying value of the solar boiler can move either up or down at each time interval, see Figure 10. Because the risks associated with the real asset can be mimicked by financial assets with similar risk characteristics, a risk-free portfolio can be created which earns the risk-free rate of return. The binomial model incorporates only energy price uncertainty. Additionally, a survey amongst homeowners was intended to disclose the consumers' perception of uncertainty in energy saving investments.

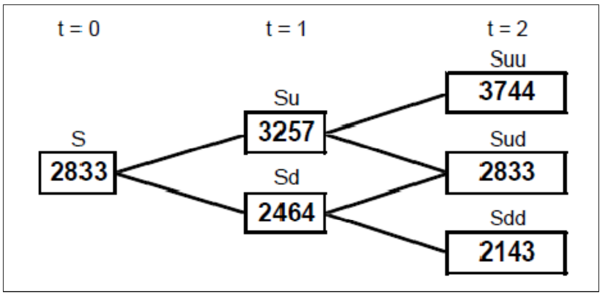

Figure 10: event tree of value of solar boiler (Van der Maaten, 2010).

The call option value determined with the binomial model is reasonably compensated by the Dutch subsidy amount. However, the survey results show that the most important risks that tend to make homeowners postpone the investment are private risks, such as uncertainty about technological development and uncertainty about moving homes before recuperating the investment. The energy price uncertainty was not seen as the main source of uncertainty. When these private risks are also incorporated into the model, the call option value will increase and probably be no longer fully compensated by the subsidy amount. This may explain the relative unpopularity of the current Dutch government subsidy program for solar hot water systems.

The study examines an energy saving measure in the residential sector and hence serves as a starting point for this research. More specific, a binomial model incorporating energy price uncertainty and using contingent claims analysis will also be used in this research. However, this research extends the analysis in several ways: from a single system with a variable time horizon to a sequence of systems with a fixed time horizon, and from a single energy saving measure to all energy saving measures available to a homeowner. In this way the contribution of options on energy saving measures to the value of an energy concept may be assessed.

2.5 Conclusions

The conclusions of this chapter are:

- The surplus value of the real option theory with respect to the conventional net present value method is that an investment opportunity is not only assessed on a now-or-never basis, but that the opportunity to wait for (even) more profitable circumstances is also assessed.
- In effect, the real option theory adds another opportunity cost of investing to the conventional investment decision rule. The present value of future profits should compensate for the investment costs as well as for the value of the investment opportunity itself. And by definition (see below), the optimal investment threshold is reached when the value of waiting has reached zero.
- The value of an investment opportunity has two components: the net present value of the investment and the value of waiting. The net present value is the net payoff to the investor if the investment is made today. The value of waiting is always greater than or equal to zero and originates primarily from the fact that waiting for more profitable circumstances reduces the probability that the investment becomes unprofitable on an *ex post* basis.
- A discrete-time model (or binomial model) is considered more appropriate than a continuous-time model to assess real options with more complex structures because it uses only elementary mathematics (instead of stochastic calculus).
- Contingent claims analysis is considered more appropriate than dynamic programming to assess real options because it treats the risks associated with an option more consistent (when the risks associated with the option may be mimicked with traded assets).
- The geometric Brownian motion is a continuous stochastic process appropriate to model the stochastic process of future revenues of a real investment.

3 Technical model of energy systems

3.1 Introduction

This chapter addresses the technical model used to determine the energy consumption of energy concepts and the potential energy savings due to energy saving measures. Section 3.2 describes energy systems and concepts. Section 3.3 elaborates on the energy consumption and potential energy savings. Section 3.4 discusses the main technical model inputs which are the reference energy concept, the main energy saving measures and the reference corner dwelling. Finally, section 3.5 concludes this chapter. The technical model results are presented in chapter 6 together with the economic model results.

3.2 Energy systems and concepts

An energy system is in this research defined as the set of spatial, constructional and installation elements on the lot of a dwelling which employ primary energy carriers from the public utility network and/or locally generated renewable energy carriers, and which provide for or determine the energy requirements of a household with regard to heating, cooling, ventilation, electricity and cooking. The physical boundaries of the energy system are in this research aligned with the boundaries of the lot of the dwelling.

Figure 11 gives a schematic overview of energy systems and their environment. The inputs to an energy system are primary and renewable energy carriers. The primary energy carriers are natural gas and electricity. These primary energy carriers are extracted from the public utility network and bring along fixed and variable energy costs. Primary energy sources are exhaustive by extraction. The renewable energy sources are internal heat production (e.g. computers and lighting), ambient heat (e.g. soil heat) and solar radiation. These renewable energy sources are locally extracted but do not bring along fixed or variable energy costs. These renewable energy sources are not exhaustive by extraction. An energy system does not necessarily employ all available energy sources.

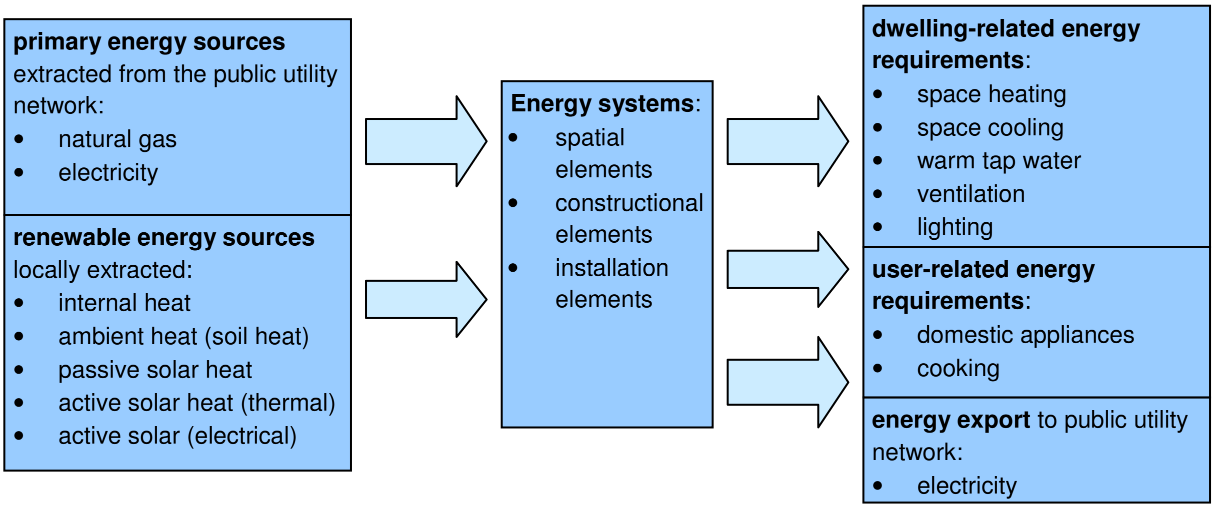

Figure 11: schematic overview of energy systems and their environment.

Energy systems comprise many spatial, constructional and installation elements. The spatial elements concern for example the size and shape of the dwelling, the number and position of windows, and possibly impeding obstacles (with regard to solar radiation). These elements are usually secured in the urban design of the district and the architectural design of the dwelling. The constructional elements concern for example the materials, composition and thickness of the shell of the dwelling. Besides the household itself, the spatial and constructional elements determine the dwelling-related energy requirements as well. The installation elements concern for example the heath generator and the ventilation system. These elements usually provide for the dwelling-related energy requirements of the household.

All elements on the lot of a dwelling (and exclusively those elements) that provide for or determine the energy requirements of a household belong to the energy system. NEN 5128 is the Dutch building code with regard to the energy consumption of dwellings and provides a practical criterion for the set of elements of an energy system. So an element on the lot of a dwelling belongs to the energy system if the element appears in NEN 5128. Appendix C contains a global overview of the elements of energy systems based on this criterion (not exhaustive). Domestic appliances do not belong to the installation elements[17].

The outputs of an energy system provide for the energy requirements of a household. These requirements are divided in dwelling-related and user-related requirements. The dwelling-related energy requirements concern space heating, space cooling, warm tap water, ventilation and lighting[18]. The user-related energy requirements concern electricity for domestic appliances and cooking. If more electricity is (locally) extracted than used by the household, the electricity surplus is exported back to the public utility network.

Energy concepts are in this research defined as energy systems whereby the system elements are filled in in a coherent manner to meet certain energy performance requirements. A known example of energy concepts is the passive dwelling concept (see section 1.1).

In a related study by Van Eck (2010) is a framework developed in order to support the reduction of energy consumption in dwellings. The integral framework includes the design phase as well as the realization and occupation phases of dwellings. In the study is a system defined as dwellings which are constructed or renovated with the main objective to reduce the energy consumption in the occupation phase of the dwellings in an efficient and effective manner. The system is divided in a physical and social system. The physical system represents the dwelling and the social system represents the influence from the environment. The physical system has five echelons:

1. Environment: type and location of the dwelling, availability of ambient heat etc.
2. Constructional aspects: volume, orientation shell of the dwelling etc.
3. Energy supply systems: heat pump, solar water heater etc.
4. Dwelling-related installations and appliances: sun screens, sanitary fittings etc.
5. User-related appliances: freezer, wash machine, computer etc.

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[17] Domestic appliances are energy consuming appliances other than the installation elements such as computers, printers, washing machines etc. (NEN 7120, 2011).

[18] The dwelling-related energy requirements also concern moistening and dehydration of the dwelling according to NEN 5128. This research does not address these energy requirements because they hardly apply to dwellings.

The system boundaries are aligned with the shell of the dwelling. The social system concerns the main actors with their interests, influence and responsibilities as well as the relevant legislation and the residents' behaviour.

Energy systems in this research resemble the physical system in the study just discussed, which builds confidence in the completeness of the technical model. Indeed, energy systems do not include the fifth echelon. Although confirmed important, this echelon is outside the scope of this research because it is not under control of a property developer. Furthermore, instead of a social system, the technical model is in this research replenished with an economic counterpart (see chapter 4). Finally, this research focuses only on newly-build dwellings.

3.3 Technical model: energy consumption

The technical model is used to determine the energy consumption of energy concepts and the potential energy savings due to energy saving measures. The technical model comprises two submodels to determine respectively the dwelling-related and user-related energy consumption.

In this research is the dwelling-related energy consumption determined analogous to the EPC method of NEN 5128[19]. The Dutch building codes prescribe that the energy performance coefficient (EPC) is determined according to NEN 5128[20]. This method is considered as generally accepted because it is also used in other sustainability instruments (e.g. GPR-building). Some cited disadvantages of the EPC method are: it supports the design phase but neglects the realization and occupation phase of dwellings; it focuses on space heating while the electricity and warm tap water account for circa 75 percent of the total energy consumption of very energy efficient dwellings; it neglects the residents' behaviour towards energy consumption (Van Eck, 2010) and it does not determine the energy consumption of very energy efficient dwellings accurate (AgentschapNL, 2010a). The first three disadvantages are not considered relevant to this research because they do not favour or prejudice individual measures assessed in this research. The fourth disadvantage is indeed relevant and therefore some results of the EPC method will be adjusted (see appendix K).

In NEN 5128 is the EPC defined as the ratio of the characteristic primary dwelling-related energy consumption to the norm primary energy consumption. The norm primary energy consumption depends on the usable floor area and the loss area of the dwelling[21]. Some relevant starting points in the EPC method are:

- The characteristic energy consumption is the expected energy consumption associated with a standardized usage of the dwelling. The standardized usage concerns the outside climate, kind of occupation, residents' behaviour etcetera. (NEN 7120, 2011).

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[19] The objective of making an integral demand on the energy efficiency of a building, instead of making separate demands on the parts of a building, is to enable the design team to realize the required energy efficiency with an optimal employment of resources (NPR 5129, 2010).

[20] NEN 5128 will be replaced in 2012 by NEN 7120 – Energieprestatie van gebouwen – bepalingsmethode. The main amendments are with regard to the ventilation losses, reference outside climate, warm tap water and cooling. This research still presumes NEN 5128.

[21] The loss area of a building is the total surface of all constructions which enclose design areas and through which thermal energy flows to or from the outside climate or to or from adjacent spaces (NEN 7120, 2011).

- The primary energy consumption concerns the energy derived from fossil fuels and is computed as the total energy consumption minus the energy yield from renewable sources such as solar radiation, ambient heat or internal heat production.
- The dwelling-related energy consumption is the energy consumption to provide for space heating, space cooling, warm tap water, ventilation, lighting, moistening and dehydration[22]. The user-related energy consumption is not included in the method.
- Standard rates are used for parameters such as the efficiencies of the technologies and the energy requirements. Innovative or unforeseen techniques with more favourable characteristics are allowed on basis of the equivalence principle. For these techniques, the building application should include an equivalence statement (i.e. documentary evidence of the characteristics of the technique).

For more detailed information about the EPC method is the reader referred to (NEN 5128, 2008) or (NPR 5129, 2010).

In this research is the user-related energy consumption based on the size and behaviour of an average Dutch household. The user-related energy consumption provides in electricity for domestic appliances and cooking. The annual electricity consumption of an average household is 2550 kWh electricity (including electric cooking) (Van Eck, 2010)[23]. This level corresponds with other studies such as (De Vries, 2010).

3.4 Technical model inputs

The main inputs to the technical model are the reference energy concept, the main energy saving measures and the reference corner dwelling. These inputs are elaborated consecutively in this section.

3.4.1 Reference energy concept

The reference level of energy concepts of newly-build dwellings is defined by the current maximum limit to the EPC as prescribed by the building codes. This means that the reference energy concept has an EPC of 0,60. More specific, the reference energy concept is based on the strategy of Bouwfonds how to accomplish an EPC of 0,60. In this way, the specifications of the reference energy concept are (Van de Griendt, 2011)[24]:

- thermal resistance of facades (roof): 4,0 (5,0) m^2K/W,
- thermal resistance of doors: 2,0 W/m^2K,
- thermal resistance of windows: 1,6 W/m^2K,
- air-permeability of shell: 0,625 dm^3/m^2s,
- heat generator: natural gas fired combination boiler,
- heat distribution system: low-temperature floor heating,
- heat regeneration system: shower water heat regeneration pipe,
- ventilation system: natural ventilation with self-regulating grilles.

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[22] This research does not address moistening and dehydration because they hardly apply to dwellings.

[23] It is remarked that the total electricity consumption of an average Dutch household in section 1.1 includes the user-related as well as the dwelling-related electricity consumption.

[24] See also the third energy package with EPC=0,60 in the Bouwfonds Classics Configurator (version 1.2). The Bouwfonds Classics Configurator is a management tool to support the communication and substantiation of the feasibility of dwellings in the design phase.

Furthermore, the reference energy concept excludes a solar water heater and PV-system but is prepared to incorporate energy saving measures in the future easily (Van de Griendt, 2011). The described specifications address the most important elements of energy concepts. The unaddressed elements are in accordance with the reference corner dwelling of SenterNovem, see section 3.4.3.

3.4.2 Main energy saving measures

A property developer may attempt to optimize the energetic or economic performance of an energy concept by taking one or more energy saving measures. An energy saving measure is defined as an upgrade of an element of the energy concept from the reference level to the energy efficient level. Typically, such a measure decreases the variable energy costs but requires upfront investment costs. The reference levels are defined by the current building codes and the energy efficient levels are chosen such that when all potential energy saving measures are taken, the variable energy costs decrease to approximately zero. It is assumed that when the variable energy costs are zero, additional energy saving measures have no economic value anymore. In this research are the main energy saving measures available to newly-build dwellings determined on basis of four criteria:

1. The measure has no significant effect outside the scope of the energy concept.
2. The measure does significantly alter the performance of the energy concept.
3. The measure is under control of a property developer.
4. The measure makes use of a proven and individual technique.

Ad 1. This research considers only energy saving measures that have no significant effect outside the scope of the energy concept. As a consequence, the spatial elements of a dwelling are not considered because these elements are secured in the urban design of the district or architectural design of the dwelling. An example of such an element is the orientation of the dwelling. Dwellings oriented towards the south tend to consume less energy for space heating and consequently have lower variable energy costs. However, changing the orientation of dwellings in a district probably has more profound and costly consequences associated with the layout and infrastructure of the district. As a consequence, the net value of adjusting the orientation of dwellings may be negative. Furthermore, the dwelling mass is also not considered. Changing the dwelling mass is possible with other materials for the facades, internal walls, floors and roof. However such an adjustment has a significant impact on the structure of the dwelling and probably also on the total costs of a dwelling.

Ad 2. This research considers only energy saving measures that have a significant impact on the energetic or economic performance of the energy concept. As a consequence, adjustments to for example the heat resistance level of the doors, variable sun screens, shower water heat regeneration system and distribution system of the space heating are not considered. The reduction of the EPC due to adjustments of these elements is smaller than 0,05.

Ad 3. This research considers only energy saving measures that are under control of a property developer. However, this criterion does not exclude any extra measures.

Ad 4. This research considers only energy saving measures that make use of individual techniques (i.e. techniques that may be applied on the lot of the dwelling) and proven techniques (techniques that are actually considered for application by Bouwfonds). As a consequence, the following techniques are not considered:

- wind power (no individual technique),
- water power (no individual technique),
- industrial residual heat (no individual technique),
- renewable biomass (no individual technique),
- combined heat and power generation (no individual technique),
- micro combined heat and power generation (no proven technique)[25],
- heat pump using outside air instead of soil heat or natural gas instead of electricity (no proven techniques)[26],
- combination solar water heater (no proven technique)[27] and
- ventilation with natural discharge (no proven technique)[28].

Table 3 on the next page shows the main energy saving measures available to newly-build dwellings which are the result of the selection procedure just described. Each measure upgrades an element of the reference energy concept to the energy efficient level. These measures are improvement of the thermal shell quality, replacement of natural ventilation with balanced ventilation, replacement of the combination boiler with a heat pump, installation of a solar water heater and installation of a PV-system. The fourth column in the table shows which energy saving measures may be postponed to the exploitation phase of the dwelling. These measures are the heat pump, solar water heater and PV-system. Postponement of these measures does not significantly alter the associated investment costs. Postponement of the other two measures (i.e. improved thermal shell quality and balanced ventilation) to the exploitation phase of the dwelling requires adjustments to structural parts of the dwelling and yields large additional investment costs. Finally, the fifth column in the table shows an indication of the feasible EPC reduction due to each measure. This reduction is determined on basis of a corner dwelling with usable a floor area of 125 square metres.

For a technical description of the main energy saving measures and associated techniques is the reader referred to appendix D. And for a substantiation of the technical specifications of the energy saving measures is the reader referred to appendix E.

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[25] The ratio investment costs to energetic performance of a micro combined heat and power generation is not yet competitive to other heath generators (Van Eck, 2010).

[26] A heat pump using outside air has a limited capacity and is not considered as a full-fledged heath generator. A natural gas heat pump has a similar efficiency as an electricity heat pump and is not considered separately.

[27] A combination solar water heater requires a supplementary heath generator and is not considered as a full-fledged heath generator.

[28] Ventilation with natural discharge is rarely applied in newly-build dwellings (AgentschapNL, 2010a).

Table 3: main energy saving measures available to newly-build dwellings.

element	available techniques		postponement possible?	ΔEPC (indication)
	reference level	energy efficient level		
constructional elements:				
thermal resistance of closed and transparent parts of shell	comfort level $R_{c;floor}$ = 4,0 m^2K/W $R_{c;roof}$ = 5,0 m^2K/W $R_{c;facade}$ = 4,0 m^2K/W U_w = 1,5 W/m^2K	passive level $R_{c;floor}$ = 6,5 m^2K/W $R_{c;roof}$ = 9,0 m^2K/W $R_{c;facade}$ = 9,0 m^2K/W U_w = 0,8 W/m^2K	no	0,11
installation elements:				
ventilation system	natural ventilation with self-regulating grilles	balanced ventilation with heat regeneration η_{hrg} = 0,95	no	0,14
heath generator	hr-combination boiler space heating: η_{opw} = 0,95 warm tap water: η_{opw} = 0,85	combination heat pump space heating η_{opw} = 1,95 warm tap water η_{opw} = 1,00	yes	0,21
solar water heater	no	A = 6,0 m^2 efficiency according NEN 5128	yes	0,11
electricity generator (PV-system)	no	A = 19,6 m^2 S_{PV} = 150 Wp/m^2 efficiency according NEN 5128	yes	0,34

Note: See for a substantiation of the technical specifications appendix E.

3.4.3 Reference corner dwelling

The energy consumption and the potential energy savings are determined on basis of the reference corner dwelling of SenterNovem[29]. The reference dwellings of SenterNovem are in the construction sector generally known as a reliable reflection of the current construction volume and consequently as a solid theoretical model. SenterNovem distinguishes several types of dwellings. The terrace dwellings represent 74 percent of the Dutch ground level access construction volume. Of these terrace dwellings, almost a quarter is a corner dwelling and slightly more than three-quarter is a mid-terrace dwelling. In this research is the corner dwelling used because this type represents almost 20 percent of the Dutch ground level access construction volume (SenterNovem, 2006).

Appendix F contains the façade views and the floor plans of the reference corner dwelling. Some relevant specifications of the reference corner dwelling are:

- The usable floor area is 125 m^2.
- The kitchen is situated at the front façade which is oriented to the north. The living room is situated at the back façade which is oriented to the south.
- The angular degree of the saddle roof is 43 degrees and the vacant roof area oriented to the south (for solar panels) approximates 33 m^2.
- The dwelling mass is based on a traditional building style (mixed heavy style).
- The dwelling includes variable sun screens on the façades oriented towards the south.

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[29] The reference dwellings of SenterNovem are drafted with the objective to enable market parties to make sensible decisions in a premature phase of the property development process and to enable research institutes to comprehend new and revised regulations in the building codes. These reference dwellings are especially developed to assess measures regarding energy consumption (SenterNovem, 2006).

3.5 Conclusions

The conclusions of this chapter are:

- The technical model is used to determine the energy consumption of energy concepts and the potential energy savings due to energy saving measures. In the model is the dwelling-related energy consumption determined analogous to the EPC method of NEN 5128 and the user-related energy consumption based on the size and behaviour of an average Dutch household.
- The main inputs to the technical model are the reference energy concept, the main energy saving measures and the reference corner dwelling.
- The main energy saving measures available to newly-build dwellings that may be postponed to the exploitation phase of the dwelling are a PV-system, heat pump and solar water heater. Postponement of these measures to the exploitation phase of the dwelling does not significantly alter the associated investment costs.

4 Economic model of energy systems

4.1 Introduction

This chapter addresses the economic model used to determine the optimal investment timings and option values of energy saving measures as well as the value of energy concepts. Section 4.2 discusses that the net present value of energy concepts is operationalized by the expected total cost of ownership of energy concepts. The expected total cost of ownership depends on the initial energy concept as well as on the expected energy saving measures that a homeowner takes during the time horizon of the energy concept. Section 4.3 elaborates on the total cost of ownership of the initial energy concept. Sections 4.4 en 4.5 elaborate on the total option value of energy saving measures. Section 4.6 discusses the discrete time intervals in the economic model. Finally, section 4.7 concludes this chapter. The economic model inputs are elaborated in chapter 5 and the economic model results are presented in chapter 6 together with the technical model results.

4.2 Value of energy concepts

The net present value of energy concepts is the sum of the discounted expected exploitation benefits, exploitation costs and investment costs incurred during the time horizon of the energy concept, see the first formula below. The expected exploitation benefits are in this research removed from the analysis because they are approximately constant across energy concepts and over time, see section 5.2. Hence, the net present value of energy concepts is operationalised by the expected total cost of ownership and the value-maximisation problem of energy concepts is turned into a cost-minimisation problem. Furthermore, the expected exploitation and investment costs depend on the initial energy concept as well as on the expected energy saving measures that a homeowner takes during the time horizon of the energy concept. Hence the total cost of ownership of energy concepts is split up in the total cost of ownership of the initial energy concept and the total option value of energy saving measures, see the second formula below. These two cost components are elaborated in the next sections.

$$\mathrm{NPV} = \sum_{t=0}^{T} \left(\frac{\mathcal{E}[\mathrm{B(t)}] - \mathcal{E}[\mathrm{C(t)}] - \mathcal{E}[\mathrm{I(t)}]}{\mathrm{e}^{(\rho * t)}} \right)$$

$$\mathrm{TCO} = \sum_{t=0}^{T} \left(\frac{-\mathrm{C_0(t)} - \mathrm{I_0(t)}}{\mathrm{e}^{(\rho * t)}} \right) + \sum_{i=1}^{n} \mathrm{F_i(0)}$$

with: NPV = net present value of energy concept [euro]
TCO = expected total cost of ownership of energy concept [euro]
t = time [years]
T = time horizon of energy concept [years]
$\varepsilon[B(t)]$ = expected exploitation benefits of energy concept at time t [euro]
$\varepsilon[C(t)]$ = expected exploitation costs of energy concept at time t [euro]
$\varepsilon[C(t)]$ = expected investment costs of energy concept at time t [euro]
ρ = discount rate [%]
$C_0(t)$ = exploitation costs of initial energy concept at time t [euro]

$I_0(t)$ = investment costs of initial energy concept at time t [euro]
i = index of energy saving measures ($i = 1, 2, ..., n$)
$F_i(0)$ = present value option on energy saving measure i [euro]

The time horizon of energy concepts is in this research assumed finite because it is not reasonable to expect the current state of affairs to be representative for an infinite number of years (e.g. with regard to the available energy saving techniques). The length of the time horizon of energy concepts is discussed in section 5.7.

4.3 Total cost of ownership of initial energy concept

The initial energy concept is the energy concept that is installed into the dwelling at the outset. The total cost of ownership of the initial energy concept is the sum of the discounted investment costs and exploitation costs associated with the initial energy concept and incurred during the time horizon of the energy concept (the exploitation benefits are not relevant). The total cost of ownership of the initial energy concept is determined with the net present value method. This method is appropriate because the initial energy concept does, by definition, not comprise any flexibility. So the total cost of ownership of the initial energy concept represents the value of the energy concept without flexibility. The algebraic definition of the total cost of ownership of the initial energy concept value is:

$$TCO_0 = \left(I_{0;con} + I_{0;add} + I_{0;utc}\right) + \sum_{t=1}^{T}\sum_{j=1}^{4}\left(-C_{0;j}(0) * e^{(\alpha_j - \rho)*t}\right)$$

with: TCO_0 = total cost of ownership of initial energy concept [euro]
$I_{0;con}$ = construction costs of initial energy concept [euro]
$I_{0;add}$ = additional costs of initial energy concept [euro]
$I_{0;utc}$ = public utility network connection costs of initial energy concept [euro]
t = time [years]
T = time horizon of energy concepts [years]
$C_{0;j}(0)$ = current level of annual exploitation costs of initial energy concept [euro]
j = index of exploitation costs components (j=var, fix, mtn, rep)
α_j = expected annual growth rate of exploitation costs component j [%]
ρ = annual discount rate [%]

The exploitation costs have four components: variable energy costs ($C_{0;var}$), fixed energy costs ($C_{0;fix}$), maintenance costs ($C_{0;mtn}$) and replacement costs ($C_{0;rep}$). The expected growth rates of prices is differentiated for variable energy prices (α_{var}) and fixed energy prices (α_{cpi}). The maintenance and replacement costs are constant in time. The exploitation costs are discounted with an exogenous (risk-adjusted) discount rate which is discussed in section 5.4.

4.4 Total option value of energy saving measures

Usually, there are several options on energy saving measures embedded in the initial energy concept. Typically an energy saving measure decreases the variable energy costs but requires upfront investment costs. An example of an energy saving measure is the installation of a PV-system. The total option value is the sum of all option values and represents the value of flexibility embedded in the energy concept. Energy concepts may comprise expansion and switch options which are elaborated in this section. Both option types are assessed with the same binomial option pricing model to uphold the comprehensibility of the economic model. The next section addresses some alternative option structures such as the single and compound option.

4.4.1 Binomial option pricing model

The optimal investment timing and option value of energy saving measures are determined with a binomial option pricing model. An option pricing model is preferred above a net present value model because it is able to address the future uncertainties and flexibility associated with options. Furthermore, a discrete model is preferred above a continuous model because it improves the comprehensibility and easily incorporates specific details of energy saving measures. The binomial model uses event trees to model the stochastic processes of:

1. the energy price index,
2. the value of an energy saving measure,
3. the value of an option on an energy saving measure

Ad 1. Stochastic energy price index

The uncertainty relating to the future prices of natural gas and electricity is in this research modelled with the energy price index. The future prices of natural gas and electricity are equal to their current prices times the energy price index. Furthermore is assumed that the energy prices (i.e. energy price index) evolve over time according to a geometric Brownian motion (see appendix A). This means that future energy prices are always positive and log-normally distributed. The binomial multiplicative process used in the binomial option pricing model includes the geometric Brownian motion as a limiting case if the associated parameters are chosen in the correct way. These parameters are elaborated in Cox et al. (1979) with the contingent claims solution procedure (see section 2.2.2). This means that in each time interval in the binomial model, the energy price index can move up or down. The magnitude of these movements increases with the volatility of the energy prices and the length of time intervals (see below). The risk-neutral probabilities of an up or down movement depend on the risk-free rate of return and on the magnitude of the movements (see below).

$$u = e^{\sigma\sqrt{\Delta t}} \text{ and } d = \frac{1}{u} = e^{-\sigma\sqrt{\Delta t}}$$

$$q = \frac{e^{r_f \Delta t} - d}{u - d} \text{ and } (1 - q) = \frac{u - e^{r_f \Delta t}}{u - d}$$

with: u = growth rate energy prices when up movement [-]
d = growth rate energy prices when down movement [-]
σ = volatility rate of energy prices [%]
Δt = length of time intervals [years]
q = risk-neutral probability of up movement
r_f = risk-free rate of return [%]

The prices of natural gas and electricity are moderately correlated, see appendix J. In this research is assumed that the two prices are perfectly correlated and is a single stochastic variable (i.e. the energy price index) used to model the uncertainty relating to both prices. The main reason for this simplification is to maintain the comprehensibility of the economic model. Two partially correlated stochastic variables may be modelled with a quadranomial model but this will severely hinder the comprehensibility of the model. Notice that this simplification does only affect options which depend on both energy prices (i.e. the option on a heat pump).

Ad 2. Stochastic value of energy saving measure

The present value of an energy saving measure in each potential state of nature depends on the annual variable energy cost savings, the expected growth rate of the energy price, the discount rate and the remaining time horizon. Because the energy prices evolve stochastically over time, the value of an energy saving measure also evolves stochastically over time. The algebraic definition of the value of an energy saving measure is:

$$V_i(t) = \sum_{u=1}^{u=T-t} \left(\Delta C_{i;var}(t) * e^{(\alpha_{var}-\rho)*u}\right) = \Delta C_{i;var}(t) * K_{var}(T-t)$$

with: $V_i(t)$ = present value of energy saving measure i at time t [euro]
i = index of energy saving measures ($i = 1, 2, ..., n$)
$(T\text{-}t)$ = remaining time horizon of energy concept [years]
$\Delta C_{i;var}(t)$ = annual variable energy cost savings at time t [euro]
α_{var} = expected annual growth rate of variable energy prices [%]
$K_{var}(T\text{-}t)$ = capitalisation factor of variable energy cost savings [-]

Capitalisation factor

The capitalisation factor is a measure for the number of discounted years in which annual exploitation cost savings are realized. The capitalisation factor depends on the growth rate of the prices, the discount rate and the remaining time horizon. Because the four components of exploitation costs have different growth rates, these components have also different capitalisation factors. The algebraic definition of the capitalisation factor is:

$$K_j(T-t) = \sum_{u=0}^{u=T-t} \left(e^{(\alpha_j-\rho)*u}\right) - 1$$

with: $K_j(T\text{-}t)$ = capitalisation factor of exploitation costs component j [-]
$(T\text{-}t)$ = remaining time horizon of energy concept [years]
j = index of exploitation costs components (j = var, fix, mtn and rep)
α_j = expected annual growth rate of exploitation costs component j [%]

Investment costs of energy saving measure

The investment costs of an energy saving measure in each time interval include the construction costs, additional costs and the present value of additional exploitation costs during the remaining time horizon of the energy concept. The additional exploitation costs concern only the fixed energy costs, maintenance costs and replacement costs because these costs evolve deterministically over time. The additional variable energy costs are included in the value of an energy saving measure because these costs evolve stochastically over time. The algebraic definition of the investment costs of an energy saving measure is:

$$\begin{aligned}I_i(t) &= \left(I_{i;con} + I_{i;add}\right)\left(1 - e^{-\rho(T-t)}\right) + \sum_{u=1}^{u=T-t}\sum_{j=2}^{j=4}\left(\Delta C_{i;j}(t) * e^{(\alpha_j-\rho)*u}\right)\\ &= \left(I_{i;con} + I_{i;add}\right)\left(1 - e^{-\rho*(T-t)}\right) + \Delta C_{i;fix}(t) * K_{cpi}(T-t)\\ &+ \left(\Delta C_{i;mtn} + \Delta C_{i;rep}\right) * K_0(T-t)\end{aligned}$$

with: $I_i(t)$ = investment costs of energy saving measure i at time t [euro]
$I_{i;con}$ = construction costs of energy saving measure i [euro]
$I_{i;add}$ = additional costs of energy saving measure i [euro]
$\Delta C_{i;j}(t)$ = additional annual exploitation costs component j at time t [euro]
α_j = expected annual growth rate of exploitation costs component j [%]
$K_j(T\text{-}t)$ = capitalisation factor of exploitation costs component j [-]
$(T\text{-}t)$ = remaining time horizon of energy concept [years]

Continuation value of energy saving measure

The exponential term right after the sum of construction and additional costs in the formula above represents the continuation value of the energy saving measure at the end of the time horizon. The sum of the book value and the replacement reservations of an installation have approximately a constant level over time. In fact, at each replacement date this level is equal to the required investment costs (I_{con} + I_{add}) and between two replacement dates this level is slightly less than the required investment costs depending on among others the depreciation scheme and interest rate. It is assumed that the continuation value of an energy saving measure is equal to the level of the required investment costs[30]. Depending on the age of the installation, this continuation value is realized by the book value or replacement reservations of the installation. So the net investment costs are:

$$I(t) = (I_{con}+I_{add})\left(1 - e^{-\rho(T-t)}\right)$$

with: $I_i(t)$ = investment costs of energy saving measure i at time t [euro]
$I_{i;con}$ = construction costs of energy saving measure i [euro]
$I_{i;add}$ = additional costs of energy saving measure i [euro]
$(T\text{-}t)$ = remaining time horizon of energy concept [years]

Ad 3. Stochastic value of option on energy saving measure

Finally, the binomial option pricing model is solved by calculating the option value of an energy saving measure at the final nodes first and then working backwards through the event tree towards the first node. In each node, the homeowner faces a binary decision problem. At the final nodes, when the homeowner cannot wait any longer, the homeowner can exercise the option (i.e. invest) or not. So the option value is the maximum of the net present value of the measure and zero, see the formula on the next page. At all other nodes, the homeowner can exercise the option or wait. When the homeowner exercises the option, he receives the net present value of the measure. When the homeowner waits, he receives the discounted

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[30] The continuation value of the energy saving measure represents the resale value of the measure at the end of the time horizon. Although the resale value may depend on many more aspects such as the depreciation scheme or the revenues of the measure, the above mentioned equality is considered sufficiently accurate. The effect of the continuation value on the current option value is small because the time horizon is relatively long.

expected option value at the next time interval. This option value is determined with contingent claims analysis. This means that the risk-free rate of interest and the risk-neutral probabilities are used to determine the option value, see the formula below. This formula implies that the homeowner exercises the option when the net present value of the measure is larger or equal to the discounted expected option value at the next time interval. Or in other words, the homeowner exercises the option when the value of waiting has decreased to zero.

$$F_i(T) = \max\left[\left(V_i(T) - I_i(T)\right); 0\right] = 0$$

$$F_i(t) = \max\left[\left(V_i(t) - I_i(t)\right); \left(\frac{q * F_i(t + \Delta t|up) + (1 - q) * F_i(t + \Delta t|down)}{e^{(r_f * \Delta t)}}\right)\right]$$

with: $F_i(t)$ = option value of energy saving measure i at time t [euro]
$V_i(t)$ = net present value of energy saving measure i at time t [euro]
$I_i(t)$ = investment costs of energy saving measure at time t [euro]
q = risk-neutral probability of up movement [%]
r_f = risk-free rate of return [%]
$F_i(t+\Delta t|up)$ = option value at the next time interval given that the energy price go up

For an overview of the formulas used to determine the value and optimal exercise timing of expansion and switch options is the reader referred to appendix G.

4.4.2 Expansion options

An expansion option is an option on an energy saving measure, whereby the measure expands the existing energy concept with a new element. Energy concepts may comprise two expansion options: the option on a PV-system and the option on a solar water heater. The model of an expansion option assumes that once the homeowner installs the first PV-system, the homeowner will replace the PV-systems until the end of the time horizon, see the timeline in Figure 12.

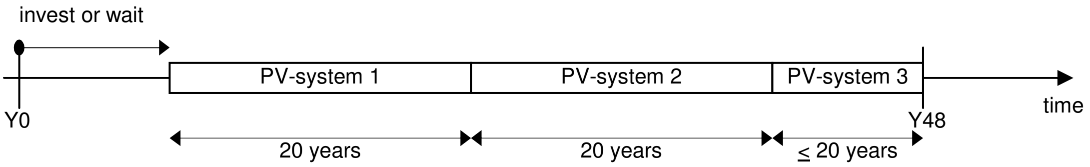

Figure 12: timeline of expansion option on PV-system.

Example expansion option on PV-system

In this example is elucidated how the value of an expansion option on a PV-system is determined. In the model of an expansion option is each PV-system replaced until the end of the time horizon of the energy concept. Assume the following input parameters (these input parameters are elaborated in chapter 5):

- Risk-free rate of return: $r_f = 4\%$.
- Risk-adjusted discount rate: $\rho = 7\%$.
- Growth rate of electricity price: $\alpha_{var} = 5\%$.
- Volatility rate of electricity price: $\sigma_{var} = 9\%$.
- Current annual variable energy costs savings: $\Delta C_{var}(0) = €502$.

- Annual maintenance costs: ΔC_{mtn} = €42.
- Annual replacement costs: ΔC_{rep} = €211.
- Upfront investment costs: I = €11.400.

Appendix H contains the binomial option pricing model of an expansion option on a PV-system. This model contains three event trees of respectively the electricity price index, the value of the PV-system and the option value of the PV-system. In each event tree are the potential states of nature appointed with coordinates (column, row). The current state has coordinate (0,0). From here, the state (1,0) is reached if the electricity price goes up and the state (1,1) is reached if the electricity price goes down etcetera. Furthermore, this model contains two tables of respectively the capitalisation factors and the total investment costs. The value of the PV-system in each potential state of nature (V(t)) is equal to the current annual variable energy cost savings ($\Delta C_{var}(0)$) times the electricity price index (epi(t)) times the capitalisation factor ($K_{var}(t)$). The total investment costs in each time interval (I(t)) are equal to the sum of the upfront investment costs (I) and the present value of all future replacement and maintenance costs ($(\Delta C_{mtn}+\Delta C_{rep})*K_0(t)$). The option value of the PV-system in each potential state of nature is equal to the maximum of the net present value of the PV-system (V(t)-I(t)) and the discounted expected option value at the next time interval ($\varepsilon[F(t+\Delta t)]*(\exp(-r_f*\Delta t)$). The green option values in the last event tree show when it is optimal to exercise the option on the PV-system.

The binomial option pricing model shows that the net present value of the PV-system is 1.290 euro. This means that it is profitable to install a PV-system at this moment. However, it is more profitable to postpone the investment and see whether the electricity price increases or decreases. The value of waiting is 3.810 euro, which makes the option to install a PV-system in the future worth 5.100 euro. The definitive results are presented and discussed in chapter 6.

4.4.3 Switch options

A switch option is an option on an energy saving measure, whereby the measure replaces an existing element of the energy concept with an alternative element with the same function. Energy concepts may comprise one switch option: the switch option on the heat pump which captures the opportunity to replace the combination boiler with a heat pump. Remember that the initial energy concept assumes a combination boiler during the complete time horizon of the energy concept. However, the homeowner may replace the combination boiler with a heat pump when that is profitable, see the timeline in Figure 13.

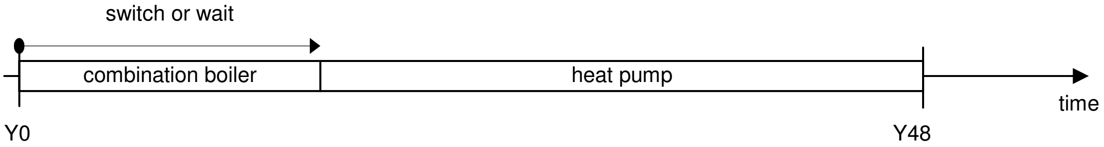

Figure 13: timeline of switch option on heat pump.

To determine the value of the switch option on the heat pump, only the additional investment costs of the heat pump with respect to the combination boiler are considered. As already discussed at the continuation value, the sum of the book value and the replacement reservations of the combination boiler are equal to the required investment costs at each replacement date and slightly less between two replacement dates.

4.5 Alternative option structures

4.5.1 Single options

The model of an expansion option on a PV-system assumes that once the homeowner installs a PV-system, the homeowner will replace the PV-systems until the end of the time horizon. In this section is a single option on a PV-system discussed. The model of a single option assumes that the homeowner does not replace the PV-system when it is worn out. Furthermore, in a single option, the time horizon relates to the maturity date of the option instead of the potential exploitation phase of the measure. As a consequence, the investment costs and value of the PV-system are independent of the remaining time horizon. A single option is also studied by Van der Maaten (2010) on basis of a solar water heater.

The revised input parameters of the PV-system with respect to section 4.4.2 are:

- The capitalisation factor of the variable energy cost savings is constant: $K_{var} = 16{,}6$[31].
- The annual replacement costs are zero.
- The capitalisation factor of the annual maintenance costs is constant: $K_0 = 10{,}9$.

The current value of the PV-system (V(0)) is 8.330 euro[32]. The value of the PV-system in each potential state of nature (V(t)) is equal to the current value (V(0)) times the electricity price index (epi(t)). Furthermore, the total investment costs (I(t)) are constant over time and are equal to the sum of the upfront investment costs (I) and the present value of annual maintenance costs ($\Delta C_{mtn} * K_0$). Appendix H0 contains the binomial option pricing model of a single option on a PV-system. Notice that the time horizon is settled to 28 years. The potential exploitation phase is in this way 48 years which is equal to the example of an expansion option on a PV-system. The net present value of the PV-system is negative 3.450 euro and it is optimal to wait and see whether the electricity prices increases. The value of waiting is 7.870 euro which makes the option to install a PV-system in the future worth 4.420 euro. Notice that the value of the single option is smaller than of the expansion option.

The advantage of a single option is the simple structure: the investment costs and value are independent of the remaining time horizon. The disadvantage of a single option is of fundamental nature. A single option does not address what happens after the first PV-system is worn out. This means that the end date of the energy saving measure is variable and depends on the actual investment date. Because of this variable end date, the single option neglects an opportunity cost of waiting when a fixed finite time horizon is assumed. If investing sooner, the exploitation phase of the energy saving measure is longer. As a consequence, single options are considered not appropriate to assess energy saving measures within a fixed finite time horizon and are not used in this research.

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[31] It is assumed that the expected growth rate of electricity prices is 5 percent, the discount rate is 7 percent and the life cycle of the measure is 20 years.

[32] $V(0) = \Delta C_{var}(0) * K_{var} = 502 * 16{,}6 = 8.330$ euro.

4.5.2 Compound options

The model of an expansion or switch option does not capture all costs saving measures owned by the homeowner. For example, the expansion option on a PV-system assumes that the homeowner will replace the PV-systems until the end of the time horizon. So only the opportunity to start a sequence of PV-systems is included. However, it may be rational to end the sequence of PV-systems when the electricity price has dropped enormously in the meantime. Such opportunities can be modelled with compound options. Compound options are options whose value is contingent on the value of other options and may be used when investment is phased (Copeland & Antikarov, 2003). When a compound option on a PV-system is exercised, the payoff to a homeowner is the sum of the net present value of the PV-system and the expected present value of a new compound option at the end of the life-cycle of the considered PV-system. The algebraic definition of this payoff is:

$$V_i(t) - I_i(t) + \sum_{u=0}^{u=(T_i/\Delta t)} \left(\frac{\sum\big(q(u) * F_i(t + T_i|u)\big)}{e^{(r_f * T_i)}} \right),$$

with: u = number of times energy price goes up during life cycle of measure [-]
T_i = life cycle of energy saving measure i [years]
$F_i(t+T_i|u)$ = option value at end of life cycle of measure given that the energy price goes up u times (during life cycle of measure) [euro]
$q(u)$ = risk-neutral probability of u up movements (during life cycle of measure)

An analysis (no details published) shows that the additional value of a compound option with respect to an expansion option is approximately three percent. This additional value is limited because the probability of a next PV-system being unprofitable conditional on this PV-system being amply profitable is negligible. So the increased accuracy with regard to the option value does not weight against the increased model complexity and hence are compound options not used in this research.

4.5.3 Risk-adjusted discount rate

In this research is the contingent claims solution procedure used to determine the option value of a measure. The essential idea in this procedure is to determine the option value by composing a risk-free portfolio of assets which earns the risk-free rate of interest. So the current option value is equal to the summed option values at the next time interval multiplied by their risk-neutral probabilities and discounted with the risk-free rate of return. For this procedure to be valid in a real option setting, a traded asset has to exist whose stochastic fluctuations are perfectly correlated to the stochastic fluctuations of the real option. Such an asset is called a spanning asset[33]. The assumption of spanning assets holds for most commodities which are typically traded on both spot and futures markets (Dixit & Pindyck, 1994). Natural gas and electricity are considered as such commodities.

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[33] For a financial call option on a traded stock, the stock itself is a spanning asset. For a real option, it more difficult to find a spanning asset.

If the risks of a real option cannot be mimicked, programming solution provides an alternative procedure to determine the option value of a measure. This procedure uses the objective probabilities of up and down movements and an exogenous risk-adjusted discount rate. This exogenous discount rate may be determined with the capital asset pricing model or based on the cost of capital. So the current option value is equal to the summed option values at the next time interval multiplied by their objective probabilities and discounted with the exogenous discount rate. The algebraic definition of the objective probabilities and the option value are:

$$p = \frac{1}{2}\left(1 + \frac{\alpha_{var}}{\sigma_{var}}\sqrt{\Delta t}\right)$$

$$F_i(t) = \max\left[(V_i(t) - I_i(t)); \left(\frac{p * F_i(t+\Delta t|up) + (1-p) * F_i(t+\Delta t|down)}{e^{(\rho * \Delta t)}}\right)\right]$$

with: α_{var} = growth rate of variable energy prices [%]
σ_{var} = volatility rate of variable energy prices [%]
Δt = length of time intervals [years]
p = objective probability of up movement
ρ = exogenous risk-adjusted discount rate

Appendix H contains a binomial model where the option value of a PV-system is determined with the objective probabilities and exogenous risk-adjusted discount rate[34]. It is observed that this procedure yields comparable results when the discount rate is 5,7 percent. This rate is actually lower than the discount rate for investments in energy saving measures, see section 5.4. This suggests that the risks associated with holding the option on a PV-system are lower than the risks associated with the PV-system itself.

Because the risks associated with the option are usually not known in advance, is the exogenous discount rate somewhat arbitrary. Furthermore, these risks change throughout the event tree and demand accordingly a variable discount rate which complicates the binomial model severely. So when spanning assets are available, contingent claims analysis treats the risks associated with a real option in more consist than dynamic programming. Hence are the objective probabilities and an exogenous discount rate not used in this research to determine the option values.

4.6 Length of time intervals

In the previous sections was the length of time intervals provisionally settled to 4 years. In that case, the expansion option value of a PV-system is 5.100 euro. Figure 14 on the next page shows the effect of the length of time intervals on the option value. It can be observed that the option value decreases with the length of time intervals. This effect is explained as follows. Smaller time intervals leads to more decision points and consequently to a more optimal decision. If the time intervals are infinitely small, the expansion option value of a PV-system is approximately 5.500 euro. In the remainder of this research is the length of time intervals settled to 1 year which is considered sufficiently accurate.

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[34] The discount rate to determine the net present value of the PV-system is still 7 percent.

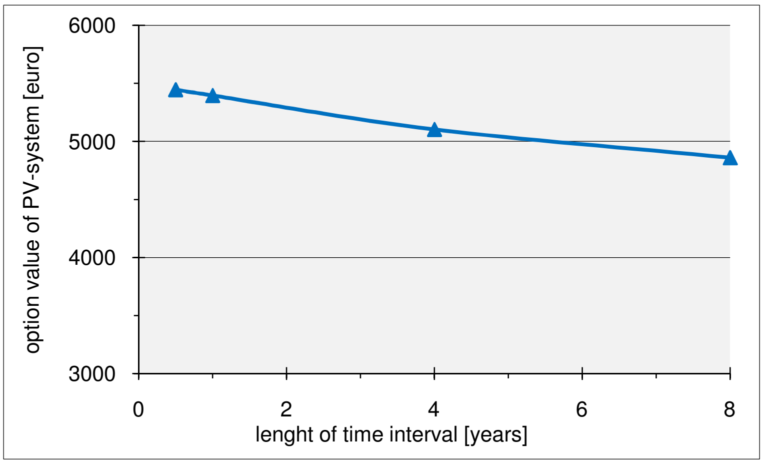

Figure 14: value of expansion option on PV-system.

4.7 Conclusions

The conclusions of this chapter are:

- The economic model is used to determine the optimal investment timings and option values of energy saving measures as well as the value of energy concepts.
- The net present value of energy concepts is operationalized by the expected total cost of ownership of energy concepts. The expected total cost of ownership is the sum of the total cost of ownership of the initial energy concept and the total option value of energy saving measures embedded in the energy concept.
- The total cost of ownership of the initial energy concept is the sum of the discounted investment costs and exploitation costs associated with the initial energy concept that is installed into the dwelling at the outset. This component represents the value of the energy concept without flexibility and is determined with a conventional net present value submodel.
- The total option value is the sum of all option values of energy saving measures embedded in the initial energy concept. This component represents the value of flexibility embedded in the energy concept and is determined with a binomial option pricing submodel.

5 Economic model inputs

5.1 Introduction

This chapter addresses the main economic model inputs. Section 5.2 elaborates on the relevant exploitation benefits and costs of energy concepts. Section 5.3 elaborates on the relevant investment costs of energy concepts. Section 5.4 elaborates on the discount rate used to obtain the net present value of energy saving measures. Sections 5.5 and 5.6 discuss the growth and volatility rates of prices. Section 5.7 elaborates on the time horizon of energy concepts. Finally, section 5.8 concludes on this chapter.

5.2 Exploitation benefits and costs of energy concepts

5.2.1 Exploitation benefits

The exploitation benefits are periodic recurring benefits associated with the usage of an energy concept. The exploitation benefits occur during the usage of the dwelling and are received by the homeowner. The exploitation benefits are a component of the value of an energy concept. The main exploitation benefits are:

- supply of heating,
- supply of cooling,
- supply of warm water,
- supply of electricity and
- supply of fresh air.

Because the main exploitation benefits are constant over time and across energy concepts, they are removed from the analysis. However, there are some exploitation benefits which are not constant across different energy concepts. Some noteworthy difference are: the level of comfort between floor heating and radiators, the level of cooling with or without a heat pump and floor heating, the level of space utilisation with or without a boiler barrel. Because these differences are small and difficult to monetarise, they are removed from the analysis.

5.2.2 Exploitation costs

The exploitation costs are periodic recurring costs associated with the ownership, maintenance and usage of an energy concept. The exploitation costs occur during the usage of the dwelling and are borne by the homeowner. The exploitation costs are a component of the value of an energy concept. NEN 2632 defines five main groups of exploitation costs for buildings:

- Fixed costs which are associated with the ownership of the building such as interest, depreciation, insurance, tax etcetera.
- Energy costs which are associated with energy usage in or outside the building such as electricity, natural gas, water etcetera.
- Maintenance costs which are associated with upholding the quality and performance of the building such as technical maintenance and cleaning the building.
- Clerical administration costs which are associated with the management of the building.
- Specific business costs which are associated with the usage of the building for business purpose such as surveillance and security.

The energy costs of natural gas and electricity consumption are included in the analysis. Because other energy costs (e.g. for water) are constant through time and across energy concept, they are excluded from the analysis. Also some fixed costs (i.e. replacement costs) and maintenance costs (i.e. technical maintenance on the building installations) are included in the analysis because they may differ across energy concepts. Exploitation costs associated with acquisition of the energy concept (e.g. interest) are included in the investment costs. Table 4 specifies the relevant exploitation costs of energy concepts.

Table 4: relevant exploitation costs of energy concepts.

main group	sub group	current level	growth rate
variable energy costs[(a)]	natural gas	€0,60 per m^3	7% per year
	electricity	€0,22 per kWh	5% per year
fixed energy costs[(a)]	natural gas	€190 per year	2% per year
	electricity	€250 per year	2% per year
	refund energy tax	-€380 per year	2% per year
replacement costs[(b)]	combination boiler, heat pump, solar water heater and PV-system	20 year life cycle	n.a.
	other elements	infinite life cycle	n.a.
(technical) maintenance costs[(c)]	combination boiler and heat pump	€150 per year	n.a.
	solar water heater and PV-system	0,5% per year	n.a.
	other elements	0	n.a.

Notes: (a) The variable and fixed energy prices reflect their current levels (www.energieprijzen.nl, 01-07-2011). The growth rates of the variable and fixed energy prices reflect respectively the historical energy price index and the historical consumer price index, see respectively section 5.5 and 5.6.

(b) The life cycles of a heat pump and combination boiler are circa 15 years and the life cycles of a solar water heater and PV-system are circa 20 years (SenterNovem, 2008). For simplicity, all these life cycles are settled to 20 years[35]. The life cycle of the other installation elements and architectural elements is assumed infinite.

(c) The maintenance costs of a solar water heater and a PV-system are negligible and a combination boiler and a heat pump require approximately the same amount of maintenance (SenterNovem, 2008). The annual maintenance costs of a combination boiler and a heat pump are settled to 150 euro (which is approximately the costs of a maintenance contract). The maintenance costs of a solar water heater and a PV-system are assumed 0,5 percent per year. This percentage is applied to the construction costs of these elements and includes tax. No maintenance costs are assumed for the other installation elements and architectural elements.

5.3 Investment costs of energy concepts

The investment costs are momentary costs associated with the realization or acquisition of an energy concept or energy-saving measure. The investments costs of the initial energy concept occur before the delivery of the building to the homeowner and are borne by the property developer. NEN 2631 defines four main groups of investment costs for buildings:

- Land costs which are associated with acquisition of the lot, destruction of existing buildings, preparation of the lot for construction and infrastructural provisions.
- Construction costs which are associated with construction of the building such as the construction costs for the shell, finishing and building installations.

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[35] The sum of the annual replacement costs is settled equivalent to the required investment costs at each replacement date. Hence the replacement costs are 0,0185 times the sum of the construction and additional costs (based on a discount rate of 9,5 percent and a life-cycle of 20 years).

- Furniture costs which are associated with furnishing the building such as furniture, carpeting, computers and business installations.
- Additional costs which are associated with realization of the building but of general kind such as fees of consultants, promotion costs, sales commission, legal charges, risk assurance, value added tax, profit & risk-compensation etcetera.

Some land costs (i.e. the energy infrastructural provisions) are included in the analysis because they may differ across energy concepts. Furthermore are the construction costs for the architectural and installation elements, as well as some additional costs included in the analysis because they may differ across energy concepts. Table 5 specifies the relevant investment costs of energy concepts.

Table 5: relevant investment costs of energy concepts.

main group	sub group	current level	growth rate
utility connection costs	public natural gas network	€700	n.a.
construction costs(a)	architectural elements	see appendix I	0
	installation elements	see appendix I	0
additional costs(b)	planning application costs	2% of construction costs	n.a.
	fee installation consultant	5% of construction costs	n.a.
	general costs developer(c)	7% of construction costs	n.a.
	value added tax	19% of total costs	n.a.

Notes: (a) The construction costs are based on quotations of Bouwfonds and three external cost databases, see for more information appendix I. The construction costs include material, labour, subcontractor and general contractor costs.
(b) The additional costs are based on the standard rates of Bouwfonds, see the Bouwfonds Classics Configurator (version 1.2).
(c) The general costs of the developer include for example sale costs, warranties, general expenses and profit.

The construction costs may increase over time due to inflation and may decrease due to technological development. It is assumed that these trends offset each other and that the construction costs are constant over time.

The additional costs apply to the case of a newly-build dwelling. A homeowner who takes an energy saving measure in the future does not incur some of the additional costs such as the planning application costs and the general costs of the property developer. On the other hand, the construction costs to a homeowner are often higher than to a property developer because of economics of scale when building a whole district. It is assumed that these disadvantages offset each other and that the investment costs are the same for newly-build dwellings and energy saving measures taken in the future[36].

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[36] The economics of scale to a property developer when building a whole district are circa 10 to 20 percent and the avoided additional costs of a homeowner are circa 14 percent. Hence, there remains a small financial advantage for newly build dwellings. However, this research considers equal investment costs as sufficiently accurate.

5.4 Discount rate

The net present value of energy saving measures depend primarily on the future energy cost savings and the discount rate. The discount rate is the rate applied to future expected cash flows to derive the present value of those cash flows and reflects the time value of money and the riskiness of those cash flows. This section discussed three starting points for the discount rate: the capital asset pricing model, the cost of capital and implicit discount rates.

The capital asset pricing model (capm) provides a theoretical solution to the problem of pricing the riskiness of a capital asset. Use of the capm for investment decision making in a corporate context is widely accepted and empirical evidence of market returns is broadly consistent with the capm (Smith and Smith, 2004). The algebraic description of the capm is:

$$\rho_j = r_f + \beta_j(r_M - r_f) \text{ with } \beta_j = \frac{\rho(r_j, r_M)\sigma_j}{\sigma_M}$$

with: ρ_j = risk-adjusted discount rate of capital asset j
r_f = risk-free rate of return
β_j = beta risk of capital asset j (i.e. nondiversifiable risk component of asset)
$(r_M - r_f)$ = market risk premium
$\rho(r_j,r_M)$ = correlation coefficient of returns on capital asset j and market portfolio
σ_j = standard deviation returns on capital asset j
σ_M = standard deviation returns on market portfolio

For investments in energy saving measures the parameters of the capm are:

- The risk-free rate of return is 3,85 percent and based on the effective interest rate on Dutch government bonds with duration of 30 years (www.dtsa.nl)[37]. This rate corresponds to other studies such as (Van der Maaten, 2010) and (Nederhorst, 2009).
- The market risk premium is 6,4 percent and based on the historical average return on the Dutch market portfolio measured against Dutch government bonds (Dimson et al., 2003). This premium falls just outside the range of historical market risk premiums of about 5 to 6 percent (Smith and Smith, 2004).
- The beta risk is 0,89 and based on the European energy industry beta (Van der Maaten, 2010). This beta falls within the range of betas of public companies in the utilities sector of about 0,47 to 0,95 (Smith and Smith, 2004).

So on basis of the capital asset pricing model, the discount rate should be 9,5 percent.

Another basis for the discount rate may be provided by the cost of capital. This is the rate of return an investor must pay to its creditors (and shareholders) for the use of their funds. When homeowners are able to finance the energy saving measures within their mortgage, the mortgage rate represents the cost of capital. So on basis of the cost of capital, the discount rate should be 5,1 percent (www.dehypotheker.nl)[38].

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[37] See the Dutch government bond DSL_NETHER3.750_15/01/42 (www.dtsa.nl, 09-08-2011).

[38] See the Aegon spaarhypotheek nieuwbouw with fixed mortgage rate for ten years (www.dehypotheker.nl, 04-10-2011).

Finally, empirical research on implicit discount rates used by consumers to evaluate energy-saving investments may also provide a basis for the discount rate. For example, Ramseier (2011) found an implicit discount rate of 2,9 percent in a preference experiment where consumers were asked to choose between two alternative energy-saving investments. This surprisingly low discount is attributed by the author to: the investments had a long time horizon; the investment attributes were described quantitatively and the investments where characterized by little uncertainty and ample information. When the same consumers were asked to trade-off money-now versus money-later, an implicit discount rate of 19,8 percent was found. In general, the results of empirical research on implicit discount rates used by consumers show wide variations and do not provide a consistent basis for the discount rate.

So the capital asset pricing model provides the upper limit (i.e. 9,5 percent) and the mortgage rate provides the lower limit (i.e. 5,1 percent) to the discount rate. In this research is the discount rate settled to 7 percent. In the sensitivity analysis in section 6.4 is the impact of the discount rate on the option value examined.

5.5 Growth and volatility rates of energy prices

The growth and volatility rates of the variable energy prices are based on historical data provided by Statistics Netherlands and SenterNovem. The data set of Statistics Netherlands covers the period 1997 till 2011 and includes among others the costs for infrastructure, supply and transport. The data set of SenterNovem covers the period 2001 to 2011. In this research are the average growth and volatility rates of both data sets used.

The growth rates are based on the mean value of the continuous growth rates. The historical mean value of the continuous growth rate of the natural gas and electricity price was respectively 0,0631 and 0,0391, see appendix J0. So the expected annual growth rate of the natural gas and electricity price is settled to respectively 7 and 5 percent. These rates correspond to other studies such as (Van der Maaten, 2010), (De Vries, 2010) and (Atriensis, 2011). In the sensitivity analysis in section 6.4 is the impact of this expected growth rate on the option value examined.

The volatility rates are based on the standard deviation of the continuous growth rates. The historical standard deviation of the continuous growth rate of the natural gas and electricity price was respectively 0,1255 and 0,0815, see appendix J. So the expected annual volatility rate of the natural gas and electricity price is settled to respectively 13 and 9 percent. These rates correspond to other studies such as (Van der Maaten, 2010). In the sensitivity analysis in section 6.4 is the impact of this volatility rate on the option value examined.

5.6 Growth rates of other prices

The expected growth rate of fixed energy costs and consumer prices is in this research also based on historical data provided by Statistics Netherlands. In the period 1996 to 2010, the mean growth rate of consumer prices was 2,06 percent per year (www.cbs.nl, 19-07-2011). In this research is the expected growth rates of fixed energy costs and consumer prices settled to 2,0 percent per year. The expected growth rate of consumer prices corresponds to other studies such as (Van der Maaten, 2010), (De Vries, 2010) and (Atriensis, 2011).

5.7 Time horizon of energy concepts

The time horizon of energy concepts is closely related to the expected life cycle of dwellings. Unfortunately, an objective measure of the expected life cycle of dwellings is not available because the average age of the actual housing stock in most EU countries is too young for useful longitudinal *ex post* analyses (Thomsen and Flier, 2006). This may explain the wide variation in quoted life cycles in practise and literature:

- Professional pre-calculations assume usually a life cycle of dwellings of 50 years. This relatively short time horizon may be explained by the decreasing financial relevance of later years due to the applied discount rate.
- Sustainability assessment methods, such as GPR-gebouw and GreenCalc, usually assume a life-cycle of dwellings of 75 years.
- Studies, such as (CPB, 2005) and (Nunen, 2008), indicate an actual mean life cycle of dwellings of 110 to 120 years. The research method of the second study is a questionnaire addressed to real estate experts.
- The actual rate of replacement of Dutch dwellings, which is less than 0,25 percent pro annum, indicates an actual mean life cycle of Dutch dwellings of 4 centuries (Thomsen and Flier, 2006).

In this research is assumed that the expected life cycle of dwellings is 120 years and that dwellings will be thoroughly renovated two to three time in their life cycle for reasons other than (the performance of) the energy concept. So the time horizon of energy concepts is settled to 48 years. A shorter time horizon will probably decrease the profitability of energy saving measures and may force suboptimal decisions with respect to the timing of energy saving measures. On the other hand, a longer horizon may decrease the reliability of parameters and assumptions. Because the length of the time horizon is somewhat subjective, the impact on the option value is examined in the sensitivity analysis in section 6.4.

5.8 Conclusions

The conclusions of this chapter are:

- The main inputs to the economic model are the exploitation costs, investment costs and time horizon of energy concepts, the growth rates and volatility rates of energy prices and the discount rate.
- The exploitation benefits of energy concepts are approximately constant across energy concepts and over time and are removed from the analysis.
- The relevant exploitation costs of energy concepts are the variable energy costs, fixed energy costs, maintenance costs and replacement costs.
- The relevant investment costs of energy concepts are the construction costs, additional costs and public utility network connection costs.

6 Model results

6.1 Introduction

This chapter addresses the results of the technical and economic model. Section 6.2 presents the results of the technical model which are the energy consumption of the reference energy concept and the energy savings associated with the main energy saving measures. Section 6.3 presents the results of the economic model which are the optimal investment timings and option values of the main energy saving measures as well as the value of the reference energy concept. Section 6.4 examines the sensitivity of option value components to variations in key model parameters. Finally, section 6.5 concludes this chapter.

6.2 Technical model results

The energy consumption of the reference energy concept and the potential energy savings due to the main energy saving measures are determined with the technical model (see chapter 3). Appendix K0 contains detailed computations of the energy consumption and potential energy savings. Of main interest is the energy extracted from the public utility network which brings along variable energy costs.

The reference energy concept has an EPC of 0,60. The annual energy extracted from the public utility network is 720 m^3 natural gas and 3892 kWh electricity (see appendix K). The total annual variable energy costs are 1.290 euro.

The reference energy concept includes three options on energy saving measures: a PV-system, heat pump and solar water heater. With these measures may the EPC of the reference energy concept be reduced to approximately -0,05. Installation of a PV-system saves 2283 kWh electricity, installation of a heat pump saves 720 m^3 natural gas but costs 1333 kWh electricity extra and installation of a solar water heater saves 192 m^3 natural gas (see appendix K). The total annual variable energy cost savings due to these three measures are 778 euro.

The data of the PV-system are independent of the other two options. On the other hand, the heat pump and the solar water heater interact. For example, a solar water heater saves 192 m^3 of natural gas which is equal to 115 euro when there is no heat pump installed and saves 623 kWh of electricity which is equal to 137 euro when a heat pump is installed. Accordingly, a heat pump saves 139 euro when there is no solar water heater installed and saves 161 euro when there is a solar water heater installed. Because the interaction between both measures is relatively small, this interaction is resolved in the following simple way. The additional energy costs savings when both measures are taken (i.e. 22 euro each year) are evenly distributed amongst both measures. So the annual variable energy cost savings due to the solar water heater and heat pump are respectively 126 and 150 euro.

6.3 Economic model results

6.3.1 Option values

In this and next subsection are respectively the option values and optimal investment timings of the energy saving measures addressed. It concerns the options on a PV-system, heat pump and solar water heater. The option values and optimal investment timings are determined with the binomial option pricing model (see chapter 4). Appendix K contains an overview of the main data of the options as well as the binomial option pricing models.

The current variable energy savings associated with the heat pump are 150 euro each year. It is assumed that the expected growth and volatility rates of these savings are equal to the rates of natural gas (i.e. respectively 7 and 13 percent). However, the growth and volatility rates of these savings depend actually on the rates of natural gas as well as electricity. The heat pump saves natural gas but costs extra electricity. By this, the rates of natural gas are leveraged by the smaller rates of electricity. Unfortunately, this leverage is not constant throughout the event tree but depends on the energy prices in each potential state of nature. Because the binomial model can handle only constant rates, the rates of natural gas are used to determine the option value of the heat pump.

Figure 15 shows the option values of the energy saving measures. The option values reflect to some extent the scale of the measures. The option value as well as the energy performance coefficient reduction is greatest for the PV-system and smallest for the solar water heater.

The option values of the PV-system and the heat pump are quite similar and discussed only for the PV-system. The option value of a measure consists of the net present value of the measure if taken today and the value of waiting. The net present value of the PV-system is positive 1.290 euro and hence it is profitable to exercise the option at this moment, which means that it is profitable to install a PV-system at this moment. However, the option value of the PV-system is 5.390 euro and hence it is even more profitable to keep the option alive and wait until the energy prices have risen sufficiently. If the PV-system is installed when the energy prices have risen sufficiently, the possibility that the measure becomes unprofitable and should not have been taken on an *ex post* basis is negligible. So waiting generates value because a better investment decision is made. So the larger option value is due to the value of waiting which is 4.100 euro.

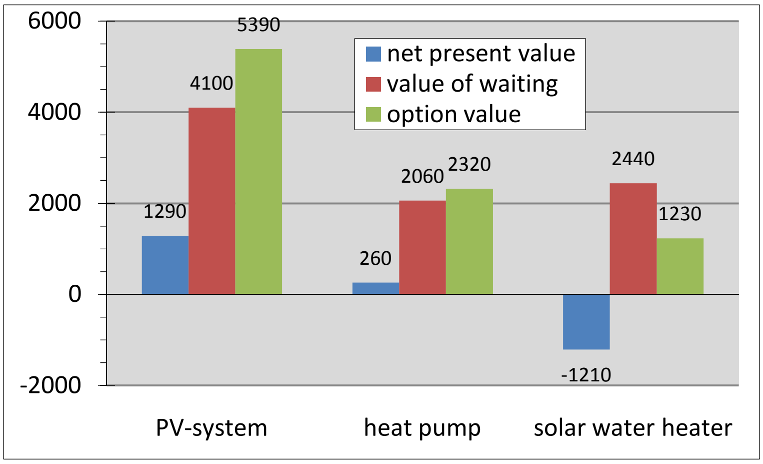

Figure 15: values of options on energy saving measures.

The net present value of the solar water heater is negative 1.210 euro and hence it is unprofitable to take this measure at this moment. However, the option value of a solar water heater is 1.230 euro and hence it is even more profitable to keep the option alive and wait until the energy prices have risen sufficiently. This positive option value is due to the value of waiting which is 2.440 euro.

6.3.2 Optimal investment timing

If an option is exercised, the option value is forgone but the net present value of the measure is retained. In effect, the value of waiting is forgone when an option is exercised. So if an option value of a measure includes significant value of waiting, it is optimal to keep the option alive until the optimal investment threshold is reached. The theoretical optimal investment threshold is reached when the value of waiting is zero and exercising the option yields exactly the same payoff as keeping the option alive. In this research is the theoretical optimal investment threshold adjusted to be applied in practise. In the adjusted investment rule is the magnitude of the value of waiting assessed relative to the net present value of the measure when taken today. When the value of waiting is very small with respect to the net present value of the measure, the value of waiting is not significant and it is reasonable to exercise the option. The significance level is subjective and in this research settled to five percent. So the practical investment threshold states that an option should be exercised, if the value of waiting is smaller than five percent of the net present value of the measure. The practical investment threshold is denoted by the optimal energy prices index (epi*).

Figure 15 shows that all options on energy saving measures carry along a significant value of waiting at this moment. This means that it is optimal to keep these options alive. In that case, the energy performance coefficient of the reference corner dwelling still complies with the current building regulations.

Furthermore is determined the expected time until the practical investment threshold is reached. For a geometric Brownian motion, the expected time until the practical investment threshold is reached may be determined with the expected first passage time from the current energy prices index (i.e. 1,0) to the optimal energy prices index (epi*), see the formula below (Mauer and Ott, 1995). From the formula can be observed that the expected time decreases with the growth rate but increases with the volatility rate of energy prices.

$$\mathcal{E}[\tilde{t}] = \frac{\ln(\mathrm{epi}^*)}{\left(\alpha_{\mathrm{var}} - \frac{\sigma_{\mathrm{var}}^2}{2}\right)}$$

with $\varepsilon[\tilde{t}]$ = expected time to reach the practical investment threshold [years]
epi* = practical investment threshold [-]
α_{var} = annual growth rate of variable energy prices [%]
σ_{var} = annual volatility rate of variable energy prices [%]

The expected time to reach the practical investment threshold is significantly smaller than the expected time to reach the theoretical optimal investment threshold. This difference is caused by the value of waiting which approaches zero very slowly when the energy prices index increases. For example, the expected time to reach the theoretical optimal investment threshold of the PV-system (i.e. significance level 0) is 31 years while the expected time to reach the practical investment threshold (i.e. significance level 5 percent) is 16 years. Furthermore, the expected time to reach the practical investment threshold of the solar water heater is 13 years and of the heat pump is 11 years, see appendix K11.0. Because the energy prices index evolves stochastically over time, the actual times to reach the investment thresholds may deviate from the expected times.

When external conditions require the energy efficiency of an energy concept to improve beyond the reference level, the property developer has to choose which option to exercise. It is then optimal to exercise the option with the smallest value of waiting first. In effect, the value of waiting forgone to obtain the required energy efficiency improvement should be considered. If for example the EPC norm is invigorated with 0,10, exercising the option on a heat pump or PV-system nullifies a value of waiting of approximately 1.100 euro while exercising the option on a solar water heater nullifies a value of waiting of 2.200 euro. For simplicity, it is assumed that the parameters of the measures are linear proportional to their scale. This means that it is optimal to exercise the option on a PV-system or heat pump before a solar water heater.

6.3.3 Value of reference energy concept

The value of energy concepts is in this research operationalized by the expected total cost of ownership. Because the operating benefits are constant across energy concepts and over time, they are not relevant and removed from the analysis. Furthermore, there are two value components of energy concepts discerned. The total cost of ownership of the initial energy concept represents the value of the energy concept without flexibility. The total option value of energy saving measures represents the value of flexibility embedded in the energy concept. Both value components are determined with the economic model (see chapter 4). Appendix M contains detailed computations of the total cost of ownership of the initial energy concept. Table 6 shows the value components of the reference energy concept and a related energy efficient concept.

Table 6: value of reference energy concept.

value component	reference energy concept	energy efficient concept
total cost of ownership initial energy concept [€]:		
- - investment costs	-13.460	-39.800(a)
- - exploitation costs	-58.530	-31.050(b)
total option value on energy saving measures [€]:		
- option value of PV-system	5.390	0
- option value of heat pump	2.320	0
- option value of solar water heater	1.230	0
expected total cost of ownership	-63.050	-70.850

Notes: (a) The investment costs are the sum of the investment costs of the reference energy concept and the energy saving measures minus the connection costs to the public natural gas network.
(b) The exploitation costs are the sum of the exploitation costs of the reference energy concept and the variable energy cost savings due to the energy saving measures.

From the table can be observed that the total option value of the main energy saving measures has a significant impact on the expected total cost of ownership of energy concepts. For the reference energy concept, the expected total cost of ownership is reduced with 12 percent by the total option value. Or put in other words, the value of the reference energy concept is increased with almost 9.000 euro by the total option value on energy saving measures. This means that the flexibility embedded in an energy concept contributes significantly to the value of the energy concept.

Furthermore can be observed from the table that the expected total cost of ownership of the reference energy concept with options on energy saving measures is 7.800 euro less than the energy efficient concept which already incorporates these energy saving measures. This difference is the net value of the value of waiting forgone by exercising the options and the avoid connection costs of the public natural gas network. So an energy concept with options on energy saving measures (i.e. a future-prepared energy concept) is more valuable than an energy efficient concept which already incorporates these energy saving measures.

6.4 Sensitivity analysis

This section examines the sensitivity of the option value components to variations in key model parameters. Addressed are consecutively the discount rate, growth rates of energy prices, volatility rates of energy prices and the time horizon of energy concepts. Appendix N contains tables with in addition to the figures presented in this section.

6.4.1 Discount rate

It is relevant to examine the effect of the discount rate on the option value components because it is plausible that the actual discount rate may deviate from the applied rate. Figure 16 shows the effect of the discount rate on the net present value of a measure and on the value of waiting. The proposed deviations are plausible because they fall within the range between the mortgage rate and the risk-adjusted discount rate according to the capital asset pricing model. From the figure can be observed that the net present value of a measure (if taken today) decreases with the discount rate. When the discount rate increases, the future energy costs savings associated with the measure become less valuable. Furthermore can be observed that the value of waiting increases with the discount rate. When the net present value of the measure becomes smaller, the probability of the investment becoming unprofitable and should not have been taken on an *ex post* basis becomes greater and accordingly the value of waiting becomes larger. The relative change in the net present value and value of waiting is larger than the relative change in the discount rate.

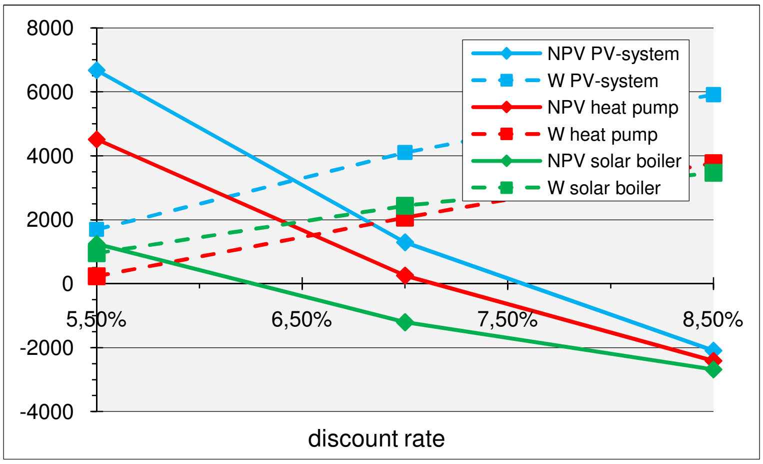

Figure 16: effect of discount rate on net present value (NPV) and value of waiting (W).

6.4.2 Growth rates of energy prices

It is relevant to examine the effect of the growth rates of the energy prices on the results of the previous section because it is plausible that the actual growth rates may deviate from the historical growth rates. Figure 17 on the next page shows the effect of the growth rates of the energy prices on the net present value of a measure and on the value of waiting. From the figure can be observed that the net present value of a measure (if taken today) increases with the growth rates of the energy prices and that the value of waiting decreases with the growth rates of the energy prices. So the qualitative effect of the growth rates of energy prices is opposite to the effect of the discount rate. When the growth rates of the energy prices increase, the present value of the future energy costs savings become more valuable. And when the net present value increases, the value of waiting decreases.

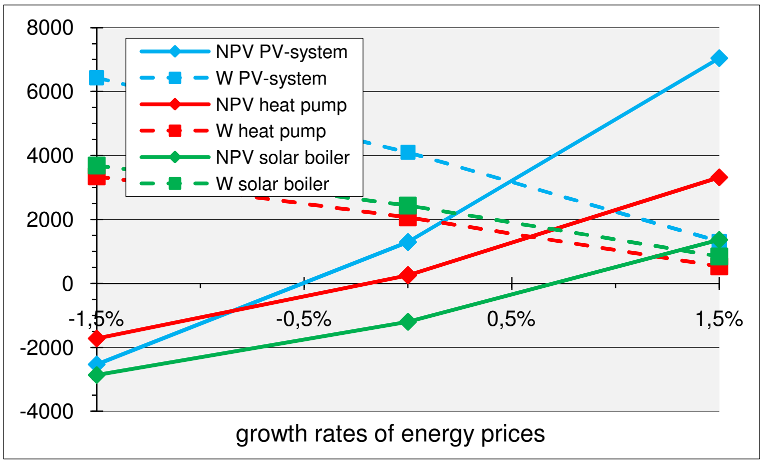

Figure 17: effect of growth rates energy prices on net present value (NPV) and value of waiting (W).

6.4.3 Volatility rates of energy prices

It is relevant to examine the effect of the volatility rates of the energy prices on the results of the previous section because it is plausible that the actual volatility rates may deviate from the historical volatility rates. Figure 18 on the next page shows the effect of the volatility rates of energy prices on the net present value of the measure and on the value of waiting. To determine the effect of the volatility rates is assumed that the applied discount rate to determine the net present value of the measure represents the risk-adjusted discount rate according to the capital asset pricing model only and not the cost of capital. In that case, the volatility rates impact the net present value of the measure via the beta-risk and risk-adjusted discount rate (see the capital asset pricing model in section 5.4). For example, if the volatility rate of the electricity price increases from 9,0 to 10,5 percent, the risk-adjusted discount rate increases from 7,0 to 7,5 percent[39].

From the figure can be observed that the volatility rates have the same qualitative effect on the net present value of a measure as the discount rate (i.e. the net present value decreases with the volatility rate). If the volatility rate increases, the beta-risk of the measure increases and the risk-adjusted discount rate increases. As a consequence, the future energy costs savings associated with the measure become less valuable. Furthermore, can be observed that the value of waiting increases with the volatility rates. Because a larger volatility rate

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[39] It is assumed that the volatility of returns on an energy saving investment depend only on the volatility of energy prices. Furthermore, it is assumed that the correlation coefficient between the returns on the investment and the market portfolio, and the volatility of returns on the market portfolio do not change. In that case, the beta-risk of an energy saving investment varies linearly with the volatility of the energy prices. If the volatility rate is increased from 9,0 to 10,5 percent, the (implied) beta-risk increases from 0,492 to 0,574 and the risk-adjusted discount rate increases from 7,0 to 7,5 percent.

increases the probability of the investment becoming unprofitable and should not have been taken on an *ex post* basis, it is more valuable to wait until the energy prices have risen sufficiently. The relative change in the net present value and value of waiting is larger than the relative change in the volatility rates.

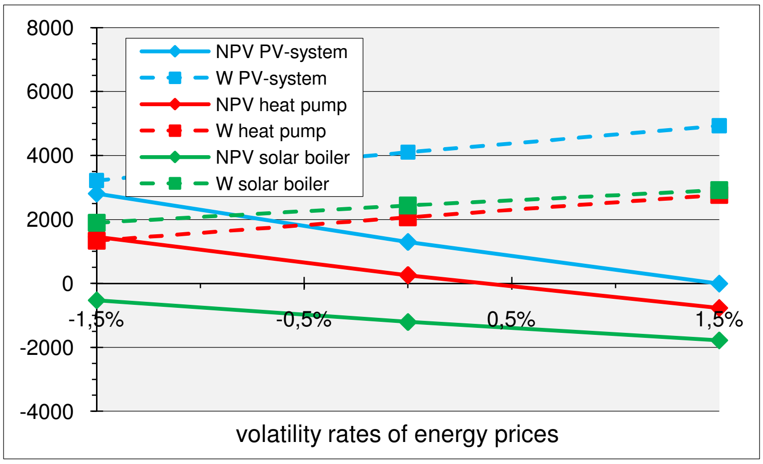

Figure 18: effect of volatility rates energy prices on net present value (NPV) and value of waiting (W).

6.4.4 Time horizon of energy concepts

In this research is the time horizon of energy concepts settled to 48 years. Because this assumption is somewhat subjective, is the effect of the length of this time horizon on the net present value of the measure and on the value of waiting examined, see Figure 19.

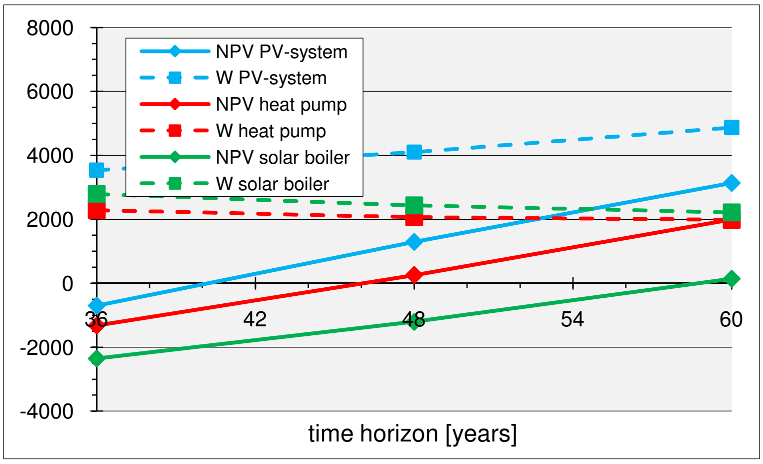

Figure 19: effect of time horizon on net present value (NPV) and value of waiting (W).

From the figure can be observed that the net present value of a measure (if taken today) increases with the time horizon. The longer the time horizon, the larger the potential exploitation phase and the larger the average expected energy cost savings associated with the measure (due to increasing energy prices). The relative change in the net present value is larger than the relative change in the time horizon. Furthermore can be observed that the value of waiting increases for the PV-system but decreases for the heat pump and the solar water heater with the time horizon. Apparently, there are two links between the value of waiting and the time horizon. The value of waiting decreases with the time horizon because the net present value increases with the time horizon. On the other hand, the value of waiting increases with the time horizon because the potential gains from waiting increase with the time horizon. The net effect is positive for the PV-system and negative for the heat pump and solar water heater.

The relative change in the value of waiting is smaller than the relative change in the time horizon.

6.5 Conclusions

The conclusions of this chapter are:

- The net present values of the PV-system and heat pump are positive and hence it is profitable to take these measures at this moment. The net present value of the solar water heater is negative and hence it is unprofitable to take this measure at this moment.
- The net present value of energy saving measures is very sensitive to variations in the discount rate, growth rates of energy prices, volatility rates of energy prices and the time horizon of the energy concept.
- The options on the main energy saving measures carry along a significant value of waiting at this moment. This means that keeping these options alive until the energy prices have risen sufficiently is more profitable than exercising these options.
- The value of waiting is sensitive to variations in the discount rate, growth rates of energy prices and volatility rates of energy prices.
- The total option value of the main energy saving measures has a significant impact on the expected total cost of ownership of the reference energy concept. This means that the flexibility embedded in an energy concept contributes significantly to the value of the energy concept.
- The practical investment thresholds of the main energy saving measures are expected to be reached in 11 to 16 years.
- The expected payback periods of the main energy saving measures at the practical investment threshold are between 9 and 13 years.

7 Survey homeowners

7.1 Introduction

This chapter addresses two surveys of homeowners. The results of the surveys are compared with the results of the economic model to find out to what extent the economic model fits the actual behaviour and preferences of homeowners. The findings may affect the final conclusions of this research. Consecutively are discussed the relevance of the economic model (section 7.2), the economic uncertainties considered by homeowners (section 7.3), the payback period demanded by homeowners (section 7.4) and the preferences of homeowners with regard to energy saving measures (section 7.5). Finally, section 7.6 concludes this chapter.

This research includes a questionnaire distributed amongst the homeowners of a small district. Because of the small scale and specific character of the district, is this survey supported with a larger scale survey. So the two sources of empirical data are:

- Survey "de Groene Kreek" (part of this research). This survey includes a questionnaire distributed amongst 65 homeowners of the district de Groene Kreek in Zoetermeer which is realized in 2006, see appendix O. The 17 respondents (response rate 26 percent) are in this research considered representative for Dutch homeowners of an energy efficient dwelling. This district was chosen because the homeowners could incorporate energy efficient measures at the construction of their dwelling or later on. So these respondents actually faced a real investment decision with regard to energy saving measures.
- Survey "Sustainable and energy efficient dwellings" (Bouwfonds Property Development, 2010). This survey includes a questionnaire which is distributed amongst an online panel. The 1012 respondents (response rate unknown) are in this research considered representative for Dutch homeowners[40].

It is remarked that the homeowners of de Groene Kreek are more familiar with energy efficient techniques and designate energy efficiency as more important than the average Dutch homeowner[41].

7.2 Relevance of economic model

To what extent does the economic model covers the decision process of homeowners? To answer this question are the arguments examined which homeowners cite to invest or postpone an energy saving investment. The results of both surveys are examined. The arguments cited by homeowners to invest or postpone an energy saving measure are aggregated and classified in:

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[40] In fact, these homeowners represent homeowners which are inclined to move to a newly-build house, which means that they have moved in the past five years or plan to move within the next five years (Bouwfonds P.D., 2010).

[41] The homeowners of de Groene Kreek are (very) familiar with the energy saving techniques described in the questionnaire and rank the energy efficiency of their dwelling as (very) important. On the other hand, only 59 percent of the Dutch homeowners took notice of the energy efficiency of their current dwelling and between 35 and 59 percent of the Dutch homeowners is not familiar with the energy saving techniques (Bouwfonds P.D., 2010).

- Soft aspects which cannot be objectively monetarized and are excluded from the economic model (e.g. “is goed voor het milieu” or “wil niet koken op electra”).
- Economic aspects which can be objectively moneterized and are included in the economic model (e.g. “een lagere energierekening”).
- Economic uncertainties which may be objectively monetarized and may be included in the economic model (e.g. “onzeker over de restwaarde bij verhuizing”).
- Barriers which are not a feature of the measure but impede homeowners to invest or enjoy the benefits (e.g. “ik kan niet betalen” of “ik ben onbekend met de techniek”). Barriers are not included in the economic model.

Table 7 shows the aggregated arguments cited by homeowners. The differences between the results of both surveys are attributed to the context and formulation of the questions in the questionnaires. The results show that the economic aspects of energy saving measures are important parameters in the decision process of homeowners. The primary reason to invest in an energy efficient dwelling is a lower energy bill while comfort, the environment and health play secondary roles (Van Estrik, 2009). So profitability increases the willingness to invest while economic uncertainty decreases the willingness to invest. These findings support the theoretical model.

Table 7: aggregated arguments to invest or postpone energy saving measures.

arguments		homeowners of de Groene Kreek [(a)]	Dutch homeowners (Bouwfonds P.D., 2010) [(b)]
to invest:	soft benefits	44%	30%
	economic benefits	53%	67%
	other	2%	3%
to postpone:	soft disadvantages	0	17%
	economic disadvantages	27%	21%
	economic uncertainties	36%	13%
	barriers	23%	24%
	other	13%	25%

Notes: In both surveys are investments in a heat pump, solar water heater and PV-system addressed.
(a) It concerns the number of cited arguments relative to all cited arguments. Some respondents have actually invested in one of these energy saving measures.
(b) It concerns the average number of respondents who cited the argument as the main reason to invest or postpone an energy saving investment. These respondents had no experience with the measures.

7.3 Economic uncertainties

Table 7 showed that economic uncertainties associated with energy saving measures accounted for 13 to 36 percent of the arguments cited by homeowners. The higher percentage in de Groene Kreek is attributed to a more economic context and formulation of the questions in the questionnaire. But what kind of uncertainties did these homeowners consider? According to the homeowners of de Groene Kreek, the main sources of uncertainty are:

- The payback period (“ik ben onzeker over de terugverdientijd”) which accounted for 23 percent of the arguments to postpone[42].

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[42] The main determinants of the payback period are the future energy prices and the actual energy savings.

- Technological development or subsidies ("ik wacht op een verbetering van de techniek of hogere subsidies") which accounted for 10 percent of the arguments to postpone.
- Moving homes ("ik ben onzeker over de restwaarde bij een eventuele verhuizing") which accounted for 3 percent of the arguments to postpone.

The relevance of uncertainties associated with energy saving measures in the decision process of homeowners is also ascertained by Van der Maaten (2010). This study includes a survey to find out what makes Dutch homeowners postpone investments in energy efficiency measures for homes in general[43]. The results of this survey show that the three most important sources of uncertainty are technological development, subsidies and moving homes. The energy prices as a source of uncertainty is only considered by few respondents which is attributed by the author to the drop of the energy prices in the wake of the current world-wide recession.

On basis of these two surveys is concluded that the four most important sources of uncertainty are the energy prices, technological development, subsidies and the resale value when moving homes. The economic model in this research includes only the energy prices as a source of uncertainty.

7.4 Payback period

The payback period is considered as an important economic criterion that homeowners use to decide whether to invest or not in energy saving measures. The economic model states that the expected payback period of energy saving measures at the practical investment threshold is between 9 and 13 years, see appendix K. Does the payback period demanded by homeowners correspond to the theoretical payback period? To answer this question are the results of the survey Sustainable and energy efficient dwellings examined.

Table 8 below shows the payback period demanded by homeowners for three energy saving measures. The majority of the homeowners demand a payback period between 2 and 10 years. The average payback period demanded by homeowners is estimated 6 years. The solar water heater has the lowest investment costs but also demands the shortest payback period. This result corresponds to a finding of Van Estrik (2009); when the payback period of an energy efficient dwelling is more than 10 years, 81 percent of the homeowners are not willing to invest. So it is concluded that the average payback period demanded by homeowners is approximately 3 to 7 years shorter than the theoretical payback period of the economic model.

Table 8: payback period demanded by homeowners (Bouwfonds P.D., 2010).

measure	investment costs	2-5 years	5-10 years	0-2 or >10 years
heat pump	€11.500	26%	41%	33%
solar boiler	€3.000	44%	27%	29%
PV-system	€8.000	29%	39%	32%

Notes: It concerns the payback periods demanded by homeowners who have no experience with these measures. The payback periods are cited after hearing the associated investment costs.

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[43] The 100 respondents (response rate 30 percent) were mostly living in big cities in the western part of the Netherlands and 19 percent of them is more familiar with energy conservation in homes and real estate in general (Van der Maaten, 2010).

7.5 Preferences of homeowners

What are the preferences of homeowners with regard to energy saving measures? To answer this question are the results of both surveys examined. Homeowners of de Groene Kreek which contemplate an additional energy saving measure, prefer a PV-system above a solar water heater and finally a heat pump. More specific, at the current energy prices, 19 percent of the respondents contemplate a PV-system and no respondents contemplate a solar water heater or heat pump. When energy prices are doubled, 50 percent of the respondents contemplate a PV-system, 13 percent contemplate a solar water heater and no respondents contemplate a heat pump. It is remarked that 46 percent of the respondents already have a heat pump and 17 percent already has a solar water heater. Because the questionnaire presents the PV-system as the measure with the longest payback period and the heat pump with the largest investment costs, these results suggests that the investment costs are at least equally important to homeowners as the payback period. This finding is supported by the results of the survey Sustainable and energy efficient dwellings. This survey finds that the popularity of the energy saving measures is inverse proportional to the investment costs (payback periods are not presented in this survey). Also Van Estrik (2009) finds that the investment costs in relation to the payback period determine the consumer preferences with regard to energy saving measures. So it is concluded that the preferences of homeowners with regard to energy saving measures depend on the investment costs as well as on the payback period. The solar boiler seems to be less popular than the heat pump and PV-system.

7.6 Conclusions

The conclusions of the survey amongst homeowners are:

- The profitability of energy saving measures increases the willingness to invest and economic uncertainties associated with energy saving measures decrease the willingness to invest of homeowners. These findings support the economic model.
- The four most important sources of uncertainty to homeowners are the energy prices, technological development, future subsidies and the resale value when moving homes. The economic model includes only energy price uncertainty.
- The average payback period of energy saving measures demanded by homeowners is approximately 6 years and the maximum payback period is 10 years. The theoretical payback period at the practical investment threshold is between 9 and 13 years. So the average payback period demanded by homeowners is approximately 3 to 7 years shorter than the theoretical payback period of the economic model.
- The preferences of homeowners with regard to energy saving measures depend on the investment costs as well as on the payback period. The solar boiler seems to be less popular than the heat pump and PV-system.

8 Conclusions

8.1 Model results

The theoretical model results are discussed according to the main research questions.

1) What are the main energy saving measures available to newly-build dwellings that may be postponed to the exploitation phase of the dwelling? The conclusions are:

- The main energy saving measures available to newly-build dwellings that may be postponed to the exploitation phase of the dwelling are a PV-system, heat pump and solar water heater (see Table 3). These measures may reduce the energy performance coefficient (EPC) of a corner dwelling from 0,60 to approximately -0,05. Postponement of these measures to the exploitation phase of the dwelling does not significantly alter the associated investment costs.

2) What are the option values of the main energy saving measures that may be postponed when energy prices uncertainty is taken into account? The conclusions are:

- The option values of these energy saving measures are significant (see Figure 15). This means that the opportunity to take these measures now or in the future is valuable. These option values consist of the net present value of the measure (if taken today) and the value of waiting.
- The net present values of the PV-system and heat pump are positive and hence it is profitable to take these measures at this moment. The net present value of the solar water heater is negative and hence it is unprofitable to take this measure at this moment (see Figure 15).
- The net present value of energy saving measures is very sensitive to variations in the discount rate, growth rates of energy prices, volatility rates of energy prices and the time horizon of the energy concept. The net present value increases with the growth rates of energy prices and the time horizon of the energy concept and decreases with the discount rate and the volatility rates of energy prices (via the beta-risk of the investment).
- The options on these energy saving measures carry along significant value of waiting at this moment (see Figure 15). The value of waiting originates from the probability that a measure, if taken today, becomes unprofitable when the energy prices drop after the investment is made and should not have been taken on an *ex post* basis. This means that keeping these options alive until the energy prices have risen sufficiently and this scenario is negligible, is more profitable than exercising these options at this moment.
- The value of waiting is sensitive to variations in the discount rate, growth rates of energy prices and volatility rates of energy prices. The value of waiting increases with the probability of an unprofitable investment on an *ex post* basis which depends on the net present value of the measure and the volatility rates of energy prices. Hence the value of waiting increases with the discount rate and decreases with the growth rates of energy prices (both via the net present value of the measure). And hence the value of waiting increases with the volatility rates of energy prices.

3) What is the optimal investment timing of the main energy saving measures that may be postponed? The conclusions are:

- Because all options on these energy saving measures carry along significant value of waiting at this moment, it is optimal to keep all options alive until the energy prices have risen sufficiently.
- The practical investment threshold of the energy saving measures is an energy price level of approximately 200 percent with respect to today's price level. The expected time to reach the practical investment threshold of the PV-system is 16 years, of the solar water heater is 13 years and of the heat pump is 11 years (see Table 14). Because the energy prices evolve stochastically over time, the actual times to reach these investment thresholds may deviate from the expected times.
- The expected payback period of the PV-system at the practical investment threshold is 9 years. The expected payback periods of the heat pump and solar water heater are 13 years (see Table 14).

4) To what extent contribute the option values of these energy saving measures to the value of an energy concept? The conclusion is:

- The total option value of the main energy saving measures has a significant impact on the expected total costs of ownership of the energy concept (see Table 6). For the reference energy concept, the expected total costs of ownership are reduced with 12 percent by the total option value. So the flexibility embedded in an energy concept contributes significantly to the value of the reference energy concept.

8.2 Managerial implications

The main managerial implication of the theoretical model results is that a future-prepared energy concept may be more valuable than an energy efficient concept because the expected total costs of ownership of a future-prepared energy concept are smaller[44]. The crux of the comparison between both energy concepts is the value of waiting. Because the additional measures in the energy efficient concept are irreversible, the associated upfront investment costs may not be recouped by the associated future energy costs savings when the energy prices drop right after the investment is made. Because the net present value of the investment is small, the scenario of an unprofitable investment on an *ex post* basis is quite likely at this moment. Hence it is profitable to wait until the energy prices have risen sufficiently and this scenario is negligible. The surplus value of the future-prepared energy concept with respect to the energy efficient concept may accumulate to 7.800 euro (see Table 6). So the main economic advantage of the future-prepared energy concept is that it has the flexibility to incorporate these measures when the energy prices rise and to postpone these measures when the energy prices drop. This implication supports the strategy of Bouwfonds how to comply with the current building codes (see section 3.4.1).

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[44] The future-prepared energy concept is equal to the reference energy concept with an option on a PV-system, heat pump and solar water heater. The energy efficient concept has already incorporated these measures.
Further, the expected total costs of ownership comprise the investment costs and expected exploitation costs associated with the energy concept as well as the expected energy costs savings associated with the energy saving measures embedded in the energy concept. The exploitation benefits are constant and hence were removed from the analysis.

Besides these sheer economic considerations, a property developer may have other relevant considerations in support of one of the two concepts. Because the upfront investment costs of a future-prepared concept are smaller than the energy efficient concept, the future-prepared concept is also more viable in the current economic climate in which consumers are reluctant to make large capital investments. This is supported by the survey amongst homeowners. At this moment, property developers experience difficulties to recharge the higher investment costs of an energy efficient concept to customers because of constrained finance opportunities due to invigorate mortgage rules and because of the current pressure on market prices of (newly-build) dwellings. Two considerations in support of the energy efficient concept are less detriment to the environment and a comfortable internal climate in the summer (which is enabled by the heat pump).

The requirements to a future-prepared energy concept in order to be able to incorporate the considered energy saving measures in the future are not explicitly addressed in this research. These requirements are: the installation infrastructure is prepared to handle these measures (i.e. idle pipes are available), the dwelling has enough vacant roof area oriented to the south for solar panels and the dwelling provides enough space to place a heat pump and boiler barrels. These requirements do not significantly alter the associated investment costs [45].

Another implication of the theoretical results is that when the energy efficiency of a newly-build dwelling is required to improve beyond the reference level, the value of waiting forgone when exercising the option on a PV-system, heat pump or solar water heater is borne by the property developer, homeowner or a third party. The energy efficiency of a newly-build dwelling may be required to improve because of external conditions such as invigorated building codes or contractual aspects following from cooperation with local government or a third party. So in order to maintain the economic viability of the property development project, the value of waiting forgone should be compensated (partially or completely) by one of the parties involved. The local government may compensate via for example a subsidy, a tax discount or a reduction in the land price. The property developer may compensate via for example economics of scale or product innovation. And finally the homeowner may compensate via for example the appreciation of the soft benefits of an energy efficient dwelling.

Furthermore, it is optimal to incorporate a PV-system or heat pump before a solar water heater when the energy efficiency of a newly-build dwelling is required to improve because in that way minimal value of waiting is forgone. Consider for example the case that the EPC norm is invigorated with 0,20 (which is planned to happen in 2015). Incorporating a heat pump or PV-system nullifies a value of waiting of respectively 2.000 or 2.400 euro. The value of waiting forgone by exercising the option on a solar water heater would be at least 4.400 euro[46].

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[45] In the case that significant additional costs have to be incurred in order to be able to incorporate a measure in the future, it is optimal to incur these costs as long as they are smaller than the option value of the measure.

[46] For simplicity, it is assumed that all economic parameters of the considered energy saving measures are linear proportional to the scale of the system.

Besides this sheer economic consideration, a property developer may have other relevant considerations in support of one of the two measures. Additional advantages of a heat pump are the comfortable internal climate in the summer and no public natural gas network required. Furthermore, the heat pump may be intuitively preferred above a PV-system and solar water heater because it concerns the primary heat generator. An additional advantage of a PV-system are the lower investment costs which are easier to recharge to consumers. Additional disadvantages of a solar water heater are the limited EPC reduction and the less popularity of the solar water heater by consumers.

A final managerial implication of the theoretical results is that options on energy saving measures available to existing dwellings will probably be exercised when their payback period is less than approximately 10 years. The intuition is that when the payback period is approximately 10 years, the net present value of the measure is relatively large and the scenario of an unprofitable investment on an *ex post* basis is negligible. Or in other words, the value of waiting is not significant anymore. This implication is supported by the survey amongst homeowners which showed that most homeowners demand a payback period of less than 10 years.

8.3 Generalizability and further research

Assumptions in this research that limit the generalizability of the results to other settings are:

- Standardized behaviour of household. The annual energy cost savings associated with the heat pump and solar water heater depend on the size and behaviour of the household. As a consequence, the quantitative results of the heat pump and solar water heater may deviate for other types of households.
- Reference corner dwelling. The annual cost savings of the heat pump depend on the volume, loss area and thermal shell quality of the dwelling. As a consequence, the quantitative results of the heat pump may deviate for other types of dwellings.
- Current energy price levels. The annual cost savings of all energy saving measures depend on the current energy price levels. As a consequence, the quantitative results of all energy saving measures are different at other energy price levels. For example, if the energy prices increase subsequent years as expected, the annual cost savings will increase and the value of waiting will decrease and become insignificant in the end.

So the quantitative results of this research may deviate for other types of dwellings, households or different energy price levels. To obtain quantitative results for these other settings, new data has to be gathered and put into the models. Data of different dwelling types or energy price levels are easily gathered and put into respectively the technical and economic model. Data of annual energy savings for different household size and behaviour will probably more difficult to obtain. Furthermore, to obtain quantitative results for other types of households, the technical model has to adjusted. However, the qualitative result of this research that options on energy saving measures with a net present value of approximately zero carry along significant value of waiting and that, as a consequence, it is optimal to keep these options alive, will probably hold in other settings.

Debatable features of the economic model with a significant impact on the results are:

- Finite time horizon. In the model is assumed that the time horizon of energy concepts is 48 years (see section 5.7). This length is somewhat subjective and the sensitivity analysis showed that the time horizon has a strong effect on the net present value of an energy saving measure but leaves the value of waiting relatively unchanged. As a consequence, the option value increases and the significance of the value of waiting decreases with the considered time horizon. However, within the range of 36 to 60 years, it is always optimal to keep the options on the energy saving measures alive.
- Discount rate. Issues related to discounting feature prominently in analyses of energy efficient technology adoption due to the difference in timing of costs and benefits (Jaffe et al., 2004). The model uses the risk-free rate of return to determine the option value of a measure because the associated risks may be hedged with other financial traded assets and uses the risk-adjusted discount rate to determine the net present value of a measure. As a consequence, the value of waiting increases with the volatility of energy prices while the net present value of a measure decreases with the volatility (see section 6.4.3). This appearing inconsistency is explained by the difference in flexibility associated with the ownership of an option and capital asset. The owner of an option can benefit from energy price increases without bearing the risk of energy price decreases. As a consequence of this a-symmetric exposure to risks, the value of waiting increases with the volatility of energy prices. On the other hand, the owner of a capital asset must bear the risk of loss in order to acquire the potential for gain. As a consequence of this symmetric exposure to risks, the net present value of a measure decreases with the volatility of energy prices (in a risk-averse setting).
- Resale value of energy concepts. In the model is assumed that the resale value of an energy concept when the homeowner removes does not affect the optimal investment timing with regard to energy saving measures (see section 1.2.3). However, the survey amongst homeowners showed that homeowners do consider the possibility that they may not recoup the investment costs when removing and hence that uncertainty associated with the resale value is an argument to postpone energy saving measures. So it is relevant to examine the effect of the resale value on the optimal investment timing in more detail. This requires an additional study to the resale value of energy concepts and an adjustment of the model based on the results of this study.
- Single stochastic variable. In the model is the stochastic evolution of the annual energy cost savings associated with the heat pump based on the growth and volatility rate of the natural gas price. In reality, this stochastic evolution is more complex and depends on the growth and volatility rates of the natural gas price as well as the electricity price. Furthermore, these energy prices are only partially correlated. So the actual stochastic process of the value of a heat pump is not fully captured by the model in this research. When two partially correlated stochastic processes for the natural gas and electricity price are used, the volatility of the annual energy cost savings

associated with the heat pump increases[47]. Standard real option theory states that the option value of an investment increases with the volatility of the investments' revenues. So it is relevant to examine the effect of two partially correlated stochastic processes instead of a single stochastic process. This effect may be examined with a quadranomial option pricing model or perhaps more challenging with an analytical approach. For more information about quadranomial models is the reader referred to (Copeland and Antikarov, 2003).

- Constant investment costs. In the model is assumed that the investment costs of energy saving measures are constant in time because the price increases due to inflation are offset by the price decreases due to product innovation. However, this assumption neglects the fact the innovation rate of a conventional technique (e.g. combination boiler) is probably lower than of an innovative technique (e.g. heat pump). Moreover, this assumption neglects the probability that subsidies will increase or decrease in the future. The survey amongst homeowners showed that homeowners consider the possibility that the investment costs may decrease in the future due to technological development or subsidies and hence that uncertainty associated with technological development or subsidies is an argument to postpone energy saving measures. So it is relevant to examine the effect of uncertain future investment costs on the optimal investment timing. This requires an additional study to the trend and volatility of technological development and subsidies, and a modification of the model based on the results of this study.

Finally, an interesting avenue of further research is to find empirical evidence for the option value of energy saving measures embedded in energy concepts in dwellings. Empirical evidence can substantiate the binomial option pricing model as well as calibrate key model parameters such as the discount rate. Brounen and Kok (2010) found already statistical evidence on a positive relation between the energy label of a dwelling, which may be considered as an aggregate measure for the energy efficiency of the dwelling, and the market price of the dwelling. However, the price premium found for energy efficient dwellings reflects more than just future energy savings alone. Based on the findings of this research, it is proposed that the price premium reflects the future energy savings associated with the energy efficient dwelling as well as the option value of energy saving measures embedded in the less energy efficient dwelling. This proposition is analogous to the finding that the market price of dwelling represents the interior space of the dwelling as well as the option to add more space to the dwelling (Eichholtz et al., 2011).

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[47] The current annual energy cost savings associated with the heat pump are 150 euro. When the growth and volatility rate of natural gas are used, these savings are after 48 years between 5 and 3860 euro. When the growth and volatility rates of natural gas and electricity are used, these savings are after 48 years between -2322 and 9611 euro.

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10 Definitions

Dwelling-related energy consumption: energy consumption to provide for space heating, space cooling, warm tap water, ventilation and lighting.

Energy concept: energy system whereby the system elements are filled in in a coherent manner to meet certain energy performance requirements.

Energy efficiency: mean energy services provided per unit of primary energy input (including usage and stoppage losses).

Energy efficient concept: energy concept which has a lower energy performance coefficient than the maximum limit prescribed by the current building codes. The current maximum limit to the energy performance coefficient is 0,60.

Energy Performance Coefficient: ratio of the characteristic primary dwelling-related energy consumption to the norm primary energy consumption (NEN 5128, 2008). The coefficient is a theoretical design value and indicates the energy efficiency of a dwelling.

Energy saving measure: an adjustment of an element of the energy concept from the reference level to an energy efficient level. Typically, such a measure decreases the variable energy costs but requires additional upfront investment costs.

Energy system: set of spatial, constructional and installation elements on the lot of a dwelling which employ primary energy carriers from the public utility network and/or locally generated renewable energy carriers, and which provide for or determine the energy requirements of a household with regard to heating, cooling, ventilation, electricity and cooking.

Expansion option: option on an energy saving measure, whereby the measure expands the existing energy concept with a new element.

Exploitation benefits (costs) : periodic recurring benefits (costs) associated with the exploitation (i.e. usage) of an energy concept.

Future-prepared energy concept: energy concept which is structurally and technically prepared to incorporate additional energy saving measures today or in the future. These measures may improve the energy efficiency of the dwelling incrementally until the energy performance coefficient is zero.

Investment costs: momentary costs associated with the acquisition or realization of an energy concept or an energy saving measure.

Net present value of energy concept: sum of expected and discounted investment costs, exploitation benefits and exploitation costs incurred during the time horizon of the energy concept. The net present value is in this research operationalized by the total cost of ownership.

Option on an energy saving measure: right, but not the obligation, to take an energy saving measure now or in the future.

Primary energy: energy derived from fossil fuels directly or indirectly (e.g. via electricity).

Real option: the right, but not the obligation, to acquire a real asset now or in the future. Usually, acquisition of the asset is irreversible and the acquisition costs of the asset are deterministic while the revenues of the asset evolve stochastically over time.

Switch option: option on an energy saving measure, whereby to the measure replaces an existing element of the energy concept with an alternative element with the same function.

Total cost of ownership of energy concept: sum of expected and discounted investment costs and exploitation costs incurred during the time horizon of the energy concept.

Total option value: sum of all individual option values on energy saving measures embedded in the initial energy concept.

User-related energy consumption: energy consumption to provide for electricity for domestic appliances and cooking.

11 Appendixes

A Geometric Brownian motion

The content of this appendix is based on (Dixit & Pindyck, 1994).

The stochastic part of a geometric Brownian motion is based on a Wiener process which is also known as a Brownian motion. A Wiener process has three important properties: it is a Markov-process, it has independent increments and changes in the process over any finite interval of time are normally distributed with a variance that increases linearly with the time interval. The increment of a Wiener process in discrete-time is defined by:

$$\Delta z = \varepsilon_t \sqrt{\Delta t}$$

with: Δz = increment of a Wiener process in discrete-time
ε_t = standard normally distributed variable (serially uncorrelated)
Δt = discrete time interval.

A geometric Brownian motion is a continuous stochastic process in which the variable may take only positive values and future values of the variable are log-normally distributed. The return on the variable is normally distributed. The geometric Brownian motion is characterized by a drift and volatility parameter and may be used to model economic variables that tend to wander far from their starting point such as the price of a stock. The process is in the long run dominated by the trend whereas the volatility dominates the short run. The geometric Brownian motion is defined by:

$$dx = \alpha x dt + \sigma x dz,$$

with x = stochastic variable
α = drift parameter,
σ = volatility parameter and
dz = the increment of a Wiener process.

Figure 20 shows an arbitrary sample path of a variable that evolves according to a geometric Brownian motion. The figure also shows the expectation as well as the confidence intervals of the stochastic variable. The parameters of the geometric Brownian motion are: $\alpha = 0{,}0075$ $\sigma = 0{,}0577$ and $x_0 = 100$.

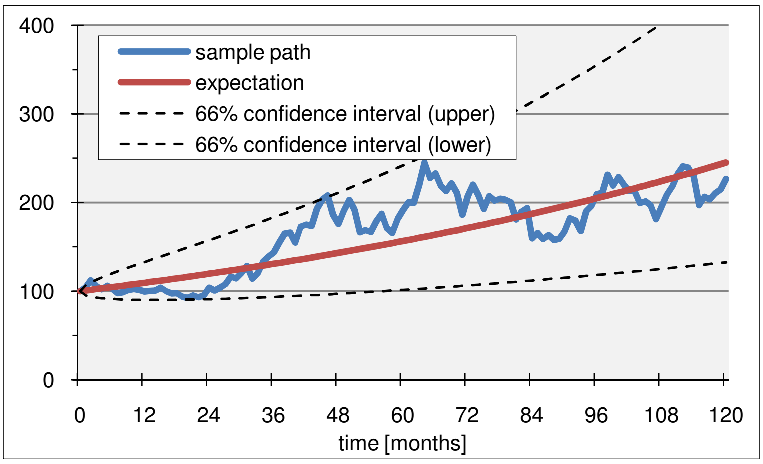

Figure 20: example of geometric Brownian motion.

B Continuous-time model of basic investment problem

The content of this appendix is based on (Dixit & Pindyck, 1994).

The general Bellman equation of holding an asset in continuous-time is:

$$\rho F(x,t) = \max_u \left\{ \pi(x,u,t) + \frac{1}{dt}\mathcal{E}[dF] \right\}.$$

with: ρ = risk-adjusted discount rate
F = value of asset
x = state variable
u = control variable
π = immediate profit flow associated with asset
$\varepsilon[dF]$ = expected capital gain on asset

The general Bellman equation is first reworked to the Bellman equation of the basic investment problem as described in section 2.3.2. The considered asset is the option to be able to produce a good which yields a profit flow. The immediate profit flow (π) associated with the option is zero. The state variable (x) is the present value of future profits (V) which is the value underlying the option. The control variable (u) is in this problem a binary variable: the firm may choose to wait and keep the investment option alive (denoted by u=0) or to invest (denoted by u=1). When the firm decides to invest, the payoff is equal to the present value of future profits (V) minus the required capital investment (I). Finally, the value of the option (F) depends on the present value of future profits only and not on time (t).

So the Bellman equation in the continuation region (i.e. waiting region) of the basic investment problem is:

$$\rho F(V) = \max \left\{ V - I, \frac{1}{dt}\mathcal{E}[dF] \right\}.$$

Then is Ito's Lemma used to expand the term $\varepsilon[dF]$. For more information about Ito's Lemma is the reader referred to (Dixit & Pindyck, 1994).

$$\text{Ito's Lemma: } dF = \left[\frac{\delta F}{\delta t} + a(V,t)\frac{\delta F}{\delta V} + \frac{1}{2}b^2(V,t)\frac{\delta^2 F}{\delta V^2} \right] dt + b(V,t)\frac{\delta F}{\delta V} dz$$

$$\text{geometric Brownian motion: } dV = \alpha V dt + \sigma V dz \rightarrow \frac{\delta F}{\delta V} = F' \text{ and } \frac{\delta^2 F}{\delta V^2} = F'' \text{ and } \frac{\delta F}{\delta t} = 0$$

$$\text{So } dF = \left[0 + \alpha V F' + \frac{1}{2}\sigma^2 V^2 F'' \right] dt + \sigma V F' dz \ \rightarrow \ \varepsilon[dF] = \left[\alpha V F' + \frac{1}{2}\sigma^2 V^2 F'' \right] dt.$$

With this result, the Bellman equation in the continuation region can be reformulated in a second-order homogeneous differential equation:

$$\frac{1}{2}\sigma^2 V^2 F'' + \alpha V F' - \rho F = 0.$$

The general solution to this differential equation is:

$$F(V) = A_1 V^{\beta 1} + A_2 V^{\beta 2}.$$

The general solution satisfies the differential equation provided that β_1 and β_2 are roots of the fundamental quadratic equation given below. In this equation, δ represents the convenience yield and is equal to $\rho - \alpha$.

$$\frac{1}{2}\sigma^2\beta(\beta - 1) + (\rho - \delta)\beta - \rho = 0.$$

Finally, the constants A_1, A_2 and the optimal investment level V^* may be solved using the three boundary conditions given below. The first condition states that the value of the investment opportunity is zero when the project value is zero. The second condition states that the firm is indifferent between waiting and investing at the optimal investment threshold. And the third condition is a technical condition to ensure that the investment rule is optimal and that no arbitrage is possible.

$$F(0) = 0 \text{ (absorbing barrier)}$$
$$F(V^*) = V^* - I \text{ (value matching)}$$
$$F'(V^*) = 1 \text{ (smooth pasting).}$$

C Elements of energy systems

Table 9: elementen van energiesystemen.

element	relevante kenmerken	invloed op
Ruimtelijke elementen:		
vorm woning	verliesoppervlakte	ruimteverwarming ruimtekoeling
	oriëntatie belemmeringshoek	ruimteverwarming ruimtekoeling passieve zonnewarmte
daken	oriëntatie helling belemmeringshoek	actieve zonnewarmte actieve zonne-energie
ramen	oppervlakte	ruimteverwarming ruimtekoeling
	oriëntatie zonwering (vast) belemmeringshoek	passieve zonnewarmte
deuren	oppervlakte	ruimteverwarming ruimtekoeling
plattegrond woning	compartimentering gebruiksoppervlakte	ruimteverwarming ruimtekoeling ventilatie verlichting warm tapwater interne warmteproductie
	lengte en diameter warm-tapwaterleidingen	warm tapwater
Bouwkundige elementen:		
gesloten delen woningschil	warmteweerstand koudebruggen	ruimteverwarming ruimtekoeling
ramen	warmtedoorgangscoëfficiënt	ruimteverwarming ruimtekoeling
	zontoetredingsfactor zonwering (variabel)	passieve zonnewarmte
deuren	warmtedoorgangscoëfficiënt	ruimteverwarming ruimtekoeling
woningschil (luchtdichtheid)	karakteristieke luchtlekkage	ruimteverwarming ruimtekoeling ventilatie
woningschil	bouwkundige massa	ruimtekoeling
Installatietechnische elementen:		
warmte-opwekker	opwekkingsrendement cv-water opwekkingsrendement tapwater toepassing energiebron(nen) warmteterugwinning	ruimteverwarming warm tapwater actieve zonnewarmte (bodem)warmte
afgiftesysteem ruimteverwarming	systeemrendement	ruimteverwarming

koude-opwekker	opwekkingsrendement cv-water toepassing energiebron(nen)	Ruimtekoeling (bodem)koude
afgiftesysteem ruimtekoeling	systeemrendement	ruimtekoeling
ventilatiesysteem	elektriciteitsverbruik ventilatoren warmteterugwinning	ventilatie ruimteverwarming
elektriciteit-opwekker (PV-panelen)	oriëntatie hellingshoek oppervlakte belemmeringshoek rendement (piekvermogen)	verlichting huishoudelijke apparaten actieve zonne-energie

D Description of main energy saving measures

In deze paragraaf zijn de belangrijkste energiebesparende maatregelen beschreven vanuit een technisch perspectief. Deze paragraaf is grotendeels gebaseerd op (AgentschapNL, 2010a) en (AgentschapNL, 2010b). Vanuit praktische overwegingen zijn de referenties naar deze bronnen achterwege gelaten. Aanvullende bronnen zijn wel in de tekst aangegeven.

Isolatiewaarde gesloten delen woningschil

De koude- en warmteverliezen door transmissie door de gesloten delen van de woningschil worden mede bepaald door de warmteweerstand van deze delen. Hoe groter de warmteweerstand, des te minder warmteverliezen ten gevolge van transmissie optreden. De warmteweerstand van een gesloten gevel wordt voornamelijk bepaald door de dikte en het materiaal van de spouwisolatie. De minimale warmteweerstand volgens het Bouwbesluit is $R_c = 2,5\ m^2K/W$. Een gangbare spouwmuur met 135 mm glaswol heeft een $R_{c;gevel} = 4,0\ m^2K/W$.

Isolatiewaarde transparante delen woningschil

De koude- en warmteverliezen door transmissie door de transparante delen van de woningschil (d.w.z. ramen en deuren) worden bepaald door de warmtedoorgangscoëfficiënt van deze delen. Hoe lager de warmtedoorgangscoëfficiënt, des te minder warmteverliezen ten gevolge van transmissie optreden. De warmtedoorgangscoëfficiënt van een raam wordt bepaald door het type glas, het kozijn en de verhouding tussen het glas- en kozijnoppervlak. De maximale warmtedoorgangscoëfficiënt volgens het Bouwbesluit is $U = 4,2\ W/m^2K$. Een gangbare combinatie voor ramen van HR++glas en een kunststof kozijn heeft een $U_w = 1,5\ W/m^2K$. Een gangbare geïsoleerde deur zonder lichtdoorlatende delen en met een houten of kunststof kozijn heeft een $U_d = 2,0\ W/m^2K$.

Luchtdichtheid woningschil

De koude- en warmteverliezen in een woning worden mede bepaald door onbewuste ventilatie via naden en kieren (ook infiltratie genoemd). De onbewuste ventilatie is afhankelijk van de luchtdichtheid uitgedrukt in de karakteristieke luchtlekkage van een woning. Hoe lager deze karakteristieke luchtlekkage, des te minder warmteverliezen door onbewuste ventilatie optreden. De maximale karakteristieke luchtlekkage volgens het Bouwbesluit is 200 dm^3/s per 500 m^3 (dit is ongeveer gelijk aan 1,04 $dm^3/s.m^2$).

Warmte-opwekker

Een warmte-opwekker gebruikt primaire en/of duurzame energiedragers om cv-water en tapwater te verwarmen. Relevante kenmerken van een warmte-opwekker zijn de aangewende energiedragers en het rendement op primaire energie. Bij het rendement wordt onderscheid gemaakt tussen het rendement op ruimteverwarming en warm tapwater. Bewezen technieken om water te verwarmen zijn een combiketel, combiwarmtepomp en zonneboilercombi. Deze technieken kunnen worden aangevuld met warmteterugwinning uit het douchewater (douche-wtw) en/of met een zonneboiler.

- Een combiketel verbrandt aardgas om het water te verwarmen. Bij een combiketel is het rendement voor ruimteverwarming aanzienlijk hoger dan voor warm tapwater. Een gangbare HR107 combiketel heeft een rendement van 97 procent voor ruimteverwarming en ongeveer 80 procent voor warm tapwater[48]. Dit rendement kan negatief worden beïnvloedt door het verbruikspatroon en de kwaliteit, onderhoud en inregeling van de apparatuur (Van Eck, 2010).

- Een combiwarmtepomp gebruikt bodemwarmte en elektriciteit om het water te verwarmen. Het systeem bestaat uit een warmtewisselaar in de bodem, en een warmtepomp en voorraadvat in de woning. Met de warmtewisselaar wordt de warmte uit de bodem ontrokken. Deze bodemwarmte heeft een lage temperatuur en wordt door de warmtepomp omgezet naar een hogere temperatuur en vervolgens opgeslagen in het voorraadvat. Gebruikelijke bestaat de warmtepomp zelf uit een verdamper, compressor en condensor, zie ook Figure 21. Vanwege het beperkte vermogen zijn combiwarmtepompen altijd voorraadtoestellen (minimaal 150 liter). Het rendement van een warmtepomp neemt sterk af naarmate het water tot een hogere temperatuur moet worden opgewarmd. Daarom vereist een warmtepomp een lage-temperatuurafgiftesysteem voor ruimteverwarming. De forfaitaire rendementen van een warmtepomp volgens NEN 5128 zijn 170 procent en 53 procent voor respectievelijk ruimteverwarming en warm tapwater. Er zijn warmtepompen beschikbaar met een rendement van 195 procent en 100 procent voor respectievelijk ruimteverwarming en warm tapwater.

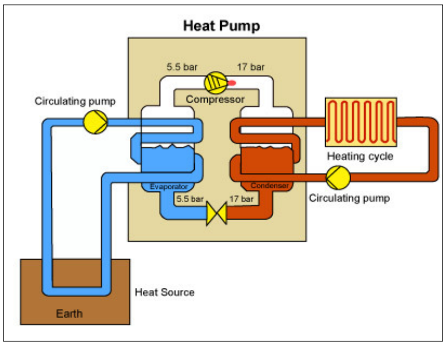

Figure 21: werking compressiewarmtepomp (www.geoprodesign.com).

- Een zonneboiler is een aanvulling op een combiketel of combiwarmtepomp. Een zonneboiler gebruikt zonnestraling om alleen tapwater te verwarmen (en geen cv-water). Het systeem bestaat uit een collector op het dak van de woning en een voorraadvat met warmtewisselaar in de woning (ongeveer 100 liter), zie ook Figure 22. De collector absorbeert de zonnestraling en verwarmt daarmee een vloeistof. Met de warmtewisselaar wordt de gewonnen warmte opgeslagen in het voorraadvat. De combiketel of combiwarmtepomp zorgt voor de naverwarming van het tapwater. Het vermeden aardgasverbruik door een zonneboiler is gelijk aan de hoeveelheid opvallende zonnestraling maal de oppervlakte van de collector en het rendement van de zonneboiler gedeeld door het opwekkingrendement van de naverwarmer en de energetische waarde van aardgas c.q. elektriciteit. De optimale oriëntatie en hellingshoek zijn richting het zuiden en 42 graden ten opzichte van horizontaal. Een

---

[48] In NEN 5128 en dit onderzoek wordt uitgegaan van het rendement op bovenwaarde waarbij de vrijkomende condensatiewarmte wordt meegeteld als aangewende energie. De totale warmte die vrijkomt bij de verbranding van aardgas (energetische bovenwaarde) is in dit geval 35,2 MJ/m^3.

collector gericht op het westen of oosten vermindert de opbrengst met circa 15 procent. Een platte collector vermindert de opbrengst met circa 10 procent. Het rendement van een zonneboiler is sterk afhankelijk de grote van de collector, in de praktijk is een rendement van 20 tot 40 procent mogelijk. Het vermeden aardgasverbruik door toepassing van een zonneboiler met een collectoroppervlakte van 3,0 m^2 bij een optimale oriëntatie en hellingshoek is zodoende ongeveer: $4000MJ/m^2 * 3,0m^2 * 0,30 / (0,85*35,2MJ/m^3) = 120\ m^3$ aardgas.

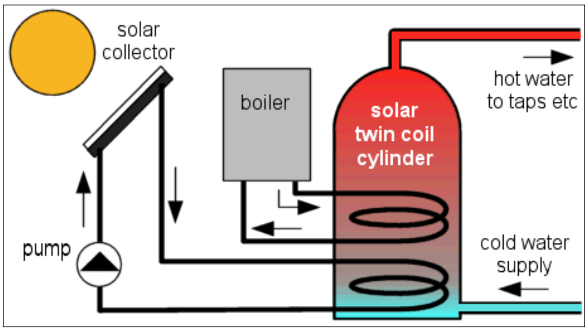

Figure 22: werking zonneboiler (www.made-in-china.com).

- Warmteterugwinning uit douchewater (douche-wtw) is een aanvulling op de combiketel, combiwarmtepomp of zonneboilercombi. Hierbij wordt met een warmtewisselaar het koude aanvoerwater voorverwarmd met het warme afvoerwater van de douche. Een gangbare douche-wtw heeft een rendement van circa 40 procent op de warmte uit het douchewater.

Afgiftesysteem ruimteverwarming

Een afgiftesysteem voor ruimteverwarming draagt de warmte van het cv-water over op personen in een ruimte door straling en convectie. Het rendement van het afgiftesysteem en de warmte-opwekker zijn afhankelijk van de temperatuur van het cv-water in het afgiftesysteem. Hoe lager de temperatuur van het cv-water, des te hoger zijn deze rendementen. Onderscheiden worden hoge-temperatuur afgiftesystemen (hta-systemen) en lage-temperatuur afgiftesystemen (lta-systemen). Bewezen technieken zijn radiatoren (zowel lta- als hta-systemen) en vloerverwarming (lta-systemen). Bijkomende voordelen van vloerverwarming ten opzichte van radiatoren zijn een hoger comfort (door een gelijkmatiger temperatuurverdeling, minder luchtbewegingen en stofverspreiding), minder kans op verbrandingsgevaar en het ontbreken van radiatoren in de ruimte.

Koude-opwekker

Een koude-opwekker gebruikt primaire en/of duurzame energiebronnen voor de opwekking van koude. Relevante kenmerken van een koude-opwekker zijn de aangewende energiedragers en het rendement op primaire energie. Indien een woning geen koelsysteem heeft, wordt in de EPC berekening een elektrische mobiele airconditioning aangenomen waarbij het rendement op primaire energie 117 procent is (zomercomfortfactor). Een warmtepomp biedt twee alternatieven voor de mobiele airconditioning: de warmtepomp in zomerbedrijf en vrije koeling. In zomerbedrijf werkt de warmtepomp als een gewone compressiekoelmachine. Het rendement van de warmtepomp voor ruimtekoeling is in dit geval ongeveer 195 procent. Bij vrije koeling hoeft alleen een circulatiepomp te draaien om het water tussen de woning en de bodem te circuleren. Hierdoor wordt warmte afgevoerd naar de bodem en koude toegevoerd aan de woning. Bij vrije koeling is het rendement van de warmtepomp ongeveer 390 procent.

Ventilatiesysteem

De koude- en warmteverliezen in een woning worden mede bepaald door bewuste ventilatie via de daarvoor bestemde ventilatievoorzieningen. Hoe meer ventilatie, des te groter zijn de koude- en warmteverliezen door bewuste ventilatie. Daarnaast wordt het elektriciteitsverbruik mede bepaald door het aantal en type ventilatoren benodigd voor ventilatie. Voor een verblijfsruimte geldt volgens het Bouwbesluit een minimale ventilatiecapaciteit van 7,0 dm^3/s en 0,7 dm^3/s per m^2.

Bewezen ventilatiesystemen zijn mechanische- en gebalanceerde ventilatie. Bij mechanische ventilatie vindt de toevoer van ventilatielucht plaats via ventilatieroosters en de afvoer via een kanalenstelsel met daaraan gekoppeld een ventilator. De ventilator is door de bewoners zelf te bedienen. Bij mechanische ventilatie zijn de warmteverliezen door ventilatie relatief groot maar het elektriciteitsverbruik van ventilatoren voor ventilatie relatief laag.

Bij gebalanceerde ventilatie vinden de toevoer én afvoer van ventilatielucht plaats via twee aparte kanalenstelsels met daaraan gekoppeld twee aparte ventilatoren. De hoeveelheid toe- en afvoerlucht is in balans. De ventilatoren zijn door de bewoners zelf te bedienen. Bij gebalanceerde ventilatie zijn de warmteverliezen door ventilatie veel kleiner maar het elektriciteitsverbruik van ventilatoren voor ventilatie relatief hoog. Dit systeem wordt gebruikelijk gecombineerd met warmteterugwinning uit de afvoerlucht. Om oververhitting in de zomer te voorkomen is het ventilatiesysteem vaak voorzien van een bypass waarmee de warmteterugwinning kan worden uitgeschakeld. Een rendement op warmteterugwinning uit de ventilatielucht is mogelijk tot 95 procent.

PV-systeem

Een PV-systeem gebruikt zonnestraling om elektriciteit op te wekken. Het systeem bestaat uit PV-panelen op het dak en een omvormer (van gelijkstroom naar wisselstroom). De PV-panelen zijn opgebouwd uit fotovoltaïsche cellen die het zonlicht absorberen en daarmee elektriciteit opwekken. Een PV-systeem kan aan het openbare elektriciteitsnet worden gekoppeld omdat deze wisselstroom levert. Het is wettelijk vastgelegd dat particulieren elektriciteit aan het openbare mogen terugleveren tot 3000 kWh (salderen).

De jaarlijkse opbrengst van een PV-systeem is gelijk aan de hoeveelheid opvallende zonnestraling maal de oppervlakte van de panelen, het piekvermogen van de panelen en het rendement van het systeem, en gedeeld door de energetische waarde van elektriciteit. De optimale oriëntatie en hellingshoek zijn richting het zuiden en 36 graden ten opzichte van horizontaal. Op horizontale panelen valt ongeveer 10 procent minder zonnestraling. Het vermogen van een PV-systeem wordt uitgedrukt in het piekvermogen [Wp] en geeft de elektriciteitsopbrengst aan per 1000 W/m^2 zonnestraling. In de praktijk is een piekvermogen van 150 W/m^2 gangbaar. De jaarlijkse opbrengst van een dergelijk PV-systeem per m^2 bij een optimale oriëntatie en hellingshoek is zodoende ongeveer: $4000 MJ/m^2 * 1{,}0 m^2 * 0{,}15 * 0{,}70 / (3{,}6 MJ/kWh) = 120$ kWh elektriciteit.

E Technical specifications of main energy saving measures

The substantiation of the technical specifications of the main energy saving measures (see Table 3) is as follows:

- The specifications of the constructional elements are based on the comfort and passive level as defined in (AgentschapNL, 2010b). The basic level is not considered because this level is insufficient to comply with the current building codes (i.e. EPC of 0,60).
- The efficiency of the self-regulating grilles is in accordance with a quality certificate (type Buva VAS II with stream valves).
- The efficiency of the ventilation heat regeneration is feasible according to various sources such as (Van Eck, 2010) and (AgentschapNL, 2010a).
- The efficiency of the combination boiler is in accordance with a quality certificate (type Intergas Kombi Kompakt HRE 36-30).
- The efficiency of the heat pump is the average efficiency according to various quality certificates (no details published).
- The efficiency of the solar water heater is in accordance with the standard efficiency in NEN 5128.
- The efficiency of the PV-system is in accordance with the standard efficiency in NEN 5128. The peak power of the PV-panels is 150 Wp/m^2 which is feasible according to various sources such as (AgentschapNL, 2010a).
- Shower heat regeneration system with η_{hrg} = 60 percent. The efficiency of the shower water heat regeneration system is in accordance with a quality certificate (type Heitech Technea douchepijp-wtw-V3-2,1m).

F Reference corner dwelling

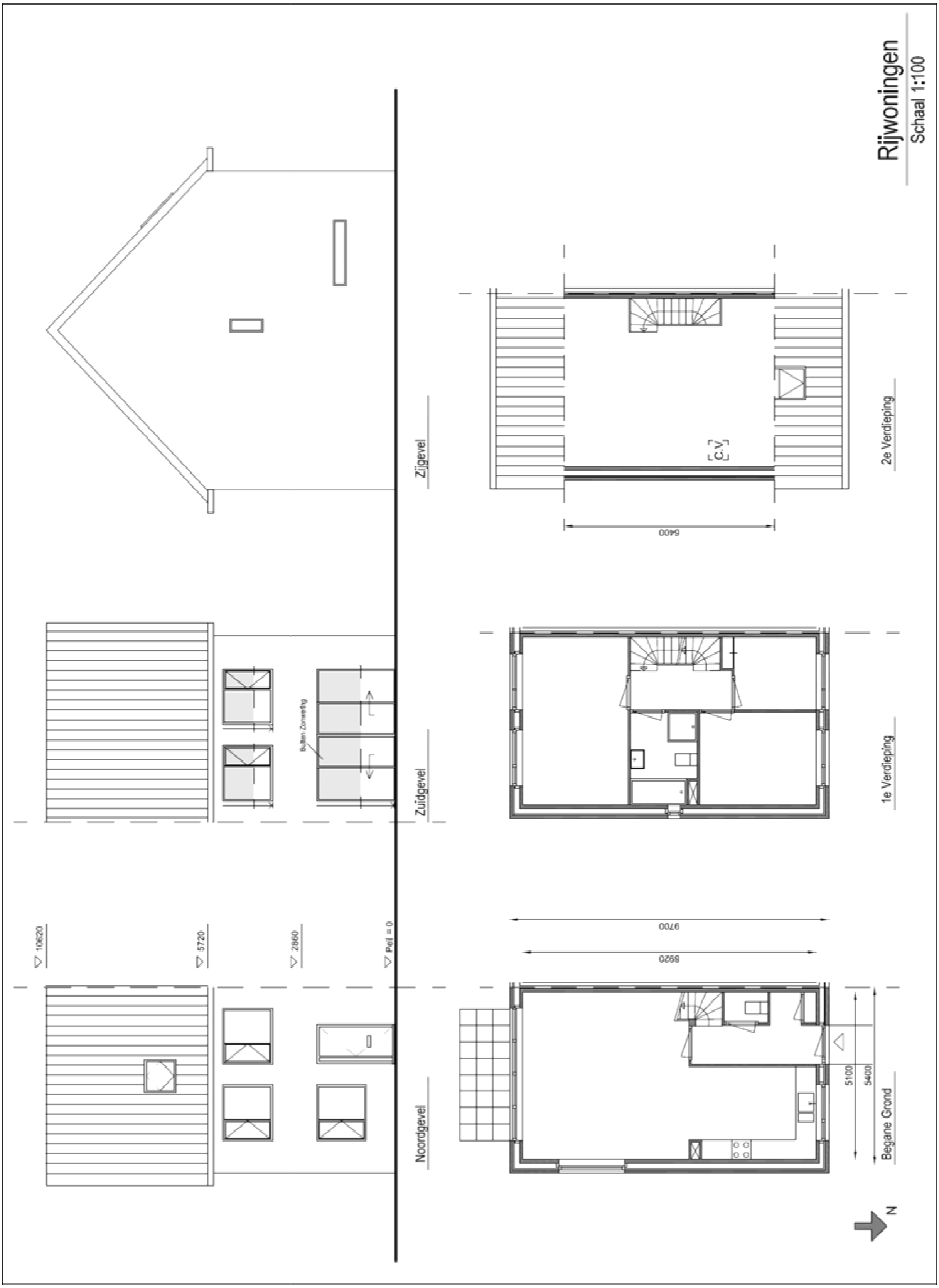

Figure 23: façade views and floor plans of the reference corner dwelling (SenterNovem, 2006).

G Formulas expansion and switch options

$$V_i(t) = \sum_{u=1}^{u=T-t} \left(\Delta C_{i;var}(t) * e^{(\alpha_{var}-\rho)*u}\right) = \Delta C_{i;var}(t) * K_{var}(T-t)$$

$$I_i(t) = \left(I_{i;con} + I_{i;add}\right)\left(1 - e^{-\rho(T-t)}\right) + \sum_{u=1}^{u=T-t} \sum_{j=2}^{j=4} \left(\Delta C_{i;j}(t) * e^{(\alpha_j-\rho)*u}\right)$$
$$= \left(I_{i;con} + I_{i;add}\right)\left(1 - e^{-\rho(T-t)}\right) + \Delta C_{i;fix}(t) * K_{cpi}(T-t)$$
$$+ \left(\Delta C_{i;mtn} + \Delta C_{i;rep}\right) * K_0(T-t)$$

$$K_j(T-t) = \sum_{u=0}^{u=T-t} \left(e^{(\alpha_j-\rho)*u}\right) - 1$$

$$F_i(T) = \max\left[\left(V_i(T) - I_i(T)\right); 0\right] = 0$$

$$F_i(t) = \max\left[\left(V_i(t) - I_i(t)\right); \left(\frac{q * F_i(t+\Delta t|up) + (1-q) * F_i(t+\Delta t|down)}{e^{(r_f*\Delta t)}}\right)\right]$$

with: $F_i(t)$ = option value of energy saving measure i at time t [euro]
$F_i(t+\Delta t|up)$ = option value at next time interval given that energy price goes up [euro]
$I_i(t)$ = investment costs of energy saving measure i at time t [euro]
$I_{i;con}$ = construction costs of energy saving measure i [euro]
$I_{i;add}$ = additional costs of energy saving measure i [euro]
$K_j(T-t)$ = capitalisation factor of exploitation costs component j [-]
$K_{var}(T-t)$ = capitalisation factor of variable energy cost savings [-]
$K_{cpi}(T-t)$ = capitalisation factor of fixed energy costs [-]
$K_0(T-t)$ = capitalisation factor of maintenance and replacement costs [-]
T = time horizon of energy system [years]
(T-t) = remaining time horizon of energy system [years]
$V_i(t)$ = net present value of energy saving measure i at time t [euro]
$\Delta C_{i;j}(t)$ = additional annual exploitation costs component j at time t [euro]
$\Delta C_{i;var}(t)$ = annual variable energy cost savings at time t [euro]
$\Delta C_{i;fix}(t)$ = additional annual fixed energy costs at time t [euro]
$\Delta C_{i;mtn}$ = additional annual maintenance costs [euro]
$\Delta C_{i;rep}$ = additional annual replacement costs [euro]
i = index of energy saving measures [i=1, 2, ..., n]
j = index of exploitation costs components [j=var, fix, mtn and rep]
q = risk-neutral probability of up movement of energy price [%]
r_f = risk-free rate of return [%]
t = time [years]
α_{var} = expected annual growth rate of variable energy cost savings [%]
α_j = expected annual growth rate of exploitation costs component j [%]
ρ = annual discount rate [%]

H Examples of binomial option pricing models (ad chapter 4)

Binomial model of expansion option on PV-system

Input parameters:			Calculated parameters:	
risk-free rate of return (rf)	0,04	0,039	growth rate up movement (u=exp(σ*√Δt))	1,188
discount rate (risk-adjusted) (ρ)	0,07	0,068	growth rate down movement (d=1/u)	0,842
exp. annual growth rate energy prices	0,05	0,049	risk-free rate per time interval (rdt=exp(rf*Δt))	1,170
exp. annual st. deviation energy prices	0,09	0,086	risk neutral prob. up movement (q=(rdt-d)/(u-d))	0,947
time horizon energy systems (T)	48	years	risk neutral prob. down movement (1-q)	0,053
investment costs measure (I)	11400	Euros	length of time intervals (Δt=T/n)	4,000
annual variable energy costs savings	502	Euros	Output parameters:	
additional annual fixed energy costs	0	Euros	net present value (V-I)	1292
additional annual maintenance costs	42	Euros	value of waiting (W)	3811
additional annual replacement costs	211	Euros	option value (F)	5103

Event tree for energy price index:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	1,00	1,19	1,41	1,68	1,99	2,37	2,81	3,34	3,97	4,72	5,60	6,66	7,91
1		0,84	1,00	1,19	1,41	1,68	1,99	2,37	2,81	3,34	3,97	4,72	5,60
2			0,71	0,84	1,00	1,19	1,41	1,68	1,99	2,37	2,81	3,34	3,97
3				0,60	0,71	0,84	1,00	1,19	1,41	1,68	1,99	2,37	2,81
4					0,50	0,60	0,71	0,84	1,00	1,19	1,41	1,68	1,99
5						0,42	0,50	0,60	0,71	0,84	1,00	1,19	1,41
6							0,36	0,42	0,50	0,60	0,71	0,84	1,00
7								0,30	0,36	0,42	0,50	0,60	0,71
8									0,25	0,30	0,36	0,42	0,50
9										0,21	0,25	0,30	0,36
10											0,18	0,21	0,25
11												0,15	0,18
12													0,13

Capitalisation factor:

t	0	4	8	12	16	20	24	28	32	36	40	44	48
Kvar	31,5	29,8	28,0	26,1	24,0	21,7	19,3	16,6	13,8	10,7	7,4	3,8	0,0
Kcpi	18,7	18,2	17,7	17,1	16,3	15,3	14,2	12,8	11,1	9,1	6,6	3,6	0,0
K0	14,1	13,9	13,7	13,4	13,0	12,5	11,8	10,9	9,7	8,1	6,1	3,5	0,0

Event tree for value of energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	15812	17787	19852	21946	23972	25788	27188	27881	27461	25369	20842	12848	0
1		12601	14064	15547	16982	18269	19261	19752	19454	17972	14765	9102	0
2			9963	11014	12031	12942	13645	13993	13782	12732	10460	6448	0
3				7803	8523	9169	9666	9913	9763	9019	7410	4568	0
4					6038	6495	6848	7022	6917	6390	5249	3236	0
5						4601	4851	4975	4900	4527	3719	2292	0
6							3437	3524	3471	3207	2634	1624	0
7								2497	2459	2272	1866	1151	0
8									1742	1609	1322	815	0
9										1140	937	577	0
10											664	409	0
11												290	0
12													0

Total investment costs of energy-saving measure:

t	0	4	8	12	16	20	24	28	32	36	40	44	48
I(t)	14521	14338	14099	13785	13374	12836	12129	11204	9990	8400	6315	3582	0

Event tree for value of option on energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	5103	6150	7410	8927	10754	12952	15059	16677	17471	16969	14527	9266	0
1		2734	3313	4014	4863	5889	7131	8548	9464	9572	8450	5520	0
2			1137	1390	1699	2077	2539	3103	3791	4332	4145	2866	0
3				250	309	381	471	581	718	887	1095	985,8	0
4					0	0	0	0	0	0	0	0	0
5						0	0	0	0	0	0	0	0
6							0	0	0	0	0	0	0
7								0	0	0	0	0	0
8									0	0	0	0	0
9										0	0	0	0
10											0	0	0
11												0	0
12													0

Binomial model of single option on PV-system

Input parameters:			Calculated parameters:	
risk-free rate of return (rf)	0,04	0,039	growth rate up movement (u=exp(σ*√Δt))	1,141
exp. annual growth rate energy prices	0,05	0,049	growth rate down movement (d=1/u)	0,877
exp. annual st. deviation energy prices	0,09	0,086	risk-free rate per time interval (rdt=exp(rf*Δt))	1,096
time horizon energy systems (T)	28	years	risk neutral prob. up movement (q=(rdt-d)/(u-d))	0,830
investment costs measure (I)	11780	Euros	risk neutral prob. down movement (1-q)	0,170
present value measure (V)	8330	Euros	length of time intervals (Δt=T/n)	2,333

Event tree for energy price index:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	1,00	1,14	1,30	1,48	1,69	1,93	2,20	2,51	2,87	3,27	3,73	4,25	4,85
1		0,88	1,00	1,14	1,30	1,48	1,69	1,93	2,20	2,51	2,87	3,27	3,73
2			0,77	0,88	1,00	1,14	1,30	1,48	1,69	1,93	2,20	2,51	2,87
3				0,67	0,77	0,88	1,00	1,14	1,30	1,48	1,69	1,93	2,20
4					0,59	0,67	0,77	0,88	1,00	1,14	1,30	1,48	1,69
5						0,52	0,59	0,67	0,77	0,88	1,00	1,14	1,30
6							0,45	0,52	0,59	0,67	0,77	0,88	1,00
7								0,40	0,45	0,52	0,59	0,67	0,77
8									0,35	0,40	0,45	0,52	0,59
9										0,31	0,35	0,40	0,45
10											0,27	0,31	0,35
11												0,24	0,27
12													0,21

Event tree for value of energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	8330	9502	10839	12364	14103	16088	18351	20933	23878	27238	31070	35442	40428
1		7303	8330	9502	10839	12364	14103	16088	18351	20933	23878	27238	31070
2			6402	7303	8330	9502	10839	12364	14103	16088	18351	20933	23878
3				5612	6402	7303	8330	9502	10839	12364	14103	16088	18351
4					4920	5612	6402	7303	8330	9502	10839	12364	14103
5						4313	4920	5612	6402	7303	8330	9502	10839
6							3781	4313	4920	5612	6402	7303	8330
7								3315	3781	4313	4920	5612	6402
8									2906	3315	3781	4313	4920
9										2548	2906	3315	3781
10											2233	2548	2906
11												1958	2233
12													1716

Event tree for value of option on energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	4422	5211	6131	7200	8441	9881	11549	13479	15709	18286	21260	24692	28648
1		3061	3660	4366	5195	6169	7307	8636	10183	11981	14069	16488	19290
2			1862	2275	2773	3371	4086	4937	5947	7139	8541	10183	12098
3				891	1125	1417	1781	2232	2790	3476	4316	5338	6571
4					252	333	439	579	765	1010	1333	1760	2323
5						0	0	0	0	0	0	0	0
6							0	0	0	0	0	0	0
7								0	0	0	0	0	0
8									0	0	0	0	0
9										0	0	0	0
10											0	0	0
11												0	0
12													0

Binomial model of expansion option on a PV-system (objective probabilities)

Input parameters:

risk-free rate of return (rf)		
discount rate (risk-adjusted) (ρ)	0,057	0,055
exp. annual growth rate energy prices	0,050	0,049
exp. annual st. deviation energy prices	0,090	0,086
time horizon energy systems (T)	48	years
investment costs measure (I)	11400	Euros
annual variable energy costs savings	502	Euros
additional annual fixed energy costs	0	Euros
additional annual maintenance costs	42	Euros
additional annual replacement costs	211	Euros

Calculated parameters:

growth rate up movement ($u=\exp(\sigma^*\sqrt{\Delta t})$)	1,188
growth rate down movement ($d=1/u$)	0,842
discount rate per time interval ($rdt=\exp(rf^*\Delta t)$)	1,248
objective prob. up movement ($q=0,5(1+\alpha/\sigma(\sqrt{\Delta t})$)	1,066
objective prob. down movement ($1-q$)	-0,066
length of time intervals ($\Delta t=T/n$)	4,000

Event tree for energy price index:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	1,00	1,19	1,41	1,68	1,99	2,37	2,81	3,34	3,97	4,72	5,60	6,66	7,91
1		0,84	1,00	1,19	1,41	1,68	1,99	2,37	2,81	3,34	3,97	4,72	5,60
2			0,71	0,84	1,00	1,19	1,41	1,68	1,99	2,37	2,81	3,34	3,97
3				0,60	0,71	0,84	1,00	1,19	1,41	1,68	1,99	2,37	2,81
4					0,50	0,60	0,71	0,84	1,00	1,19	1,41	1,68	1,99
5						0,42	0,50	0,60	0,71	0,84	1,00	1,19	1,41
6							0,36	0,42	0,50	0,60	0,71	0,84	1,00
7								0,30	0,36	0,42	0,50	0,60	0,71
8									0,25	0,30	0,36	0,42	0,50
9										0,21	0,25	0,30	0,36
10											0,18	0,21	0,25
11												0,15	0,18
12													0,13

Capitalisation factor:

t	0	4	8	12	16	20	24	28	32	36	40	44	48
Kvar	31,5	29,8	28,0	26,1	24,0	21,7	19,3	16,6	13,8	10,7	7,4	3,8	0,0
Kcpi	18,7	18,2	17,7	17,1	16,3	15,3	14,2	12,8	11,1	9,1	6,6	3,6	0,0
K0	14,1	13,9	13,7	13,4	13,0	12,5	11,8	10,9	9,7	8,1	6,1	3,5	0,0

Event tree for value of energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	15812	17787	19852	21946	23972	25788	27188	27881	27461	25369	20842	12848	0
1		12601	14064	15547	16982	18269	19261	19752	19454	17972	14765	9102	0
2			9963	11014	12031	12942	13645	13993	13782	12732	10460	6448	0
3				7803	8523	9169	9666	9913	9763	9019	7410	4568	0
4					6038	6495	6848	7022	6917	6390	5249	3236	0
5						4601	4851	4975	4900	4527	3719	2292	0
6							3437	3524	3471	3207	2634	1624	0
7								2497	2459	2272	1866	1151	0
8									1742	1609	1322	815	0
9										1140	937	577	0
10											664	409	0
11												290	0
12													0

Total investment costs of energy-saving measure:

t	0	4	8	12	16	20	24	28	32	36	40	44	48
I(t)	14521	14338	14099	13785	13374	12836	12129	11204	9990	8400	6315	3582	0

Event tree for value of option on energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	5088	6135	7397	8917	10748	12952	15059	16677	17471	16969	14527	9266	0
1		2872	3447	4136	4961	5949	7132	8548	9464	9572	8450	5520	0
2			1357	1611	1912	2270	2694	3196	3791	4332	4145	2866	0
3				363	425	498	583	682	799	935	1095	986	0
4					0	0	0	0	0	0	0	0	0
5						0	0	0	0	0	0	0	0
6							0	0	0	0	0	0	0
7								0	0	0	0	0	0
8									0	0	0	0	0
9										0	0	0	0
10											0	0	0
11												0	0
12													0

I Construction costs

Table 10: construction costs of main energy saving measures.

element	technical specifications		construction costs$^{(a)}$ [€]
shell of dwelling - incremental costs of appreciation from comfort level to passive level	comfort level	passive level	9.200
	$R_{c;floor}$ = 4,0 m^{2}K/W $R_{c;roof}$ = 5,0 m^{2}K/W $R_{c;facade}$ = 4,0 m^{2}K/W U_w = 1,5 W/m^{2}K q_{v10kar} = 0,625 dm^3/s.m^2	$R_{c;floor}$ = 6,5 m^{2}K/W $R_{c;roof}$ = 9,0 m^{2}K/W $R_{c;facade}$ = 9,0 m^{2}K/W U_w = 0,8 W/m^{2}K q_{v10kar} = 0,150 dm^3/s.m^2	
ventilation system - incremental costs of appreciation from natural to balanced including heat regeneration (hrg)	natural ventilation	balanced ventilation	3.200
	self-regulating grilles	heat regeneration: η_{hrg} = 0,95 bypass in summer	
combination boiler	power circa 28 kW space heating: η_{opw} = 0,95 tap water: η_{opw} = 0,85		2.600
heat pump	power circa 5 kW space heating: η_{opw} = 1,95 tap water: η_{opw} = 1,00 boiler barrel 150 litre		10.000$^{(b)}$
solar water heater	A_{panels} = 6,0 m^2 boiler barrel 300 litre		4.200
PV-system	A_{panels} = 19,6 m^2 S_{PV} = 150 Wp/m^2 central inverter		8.400

Notes: The construction costs are based on quotations of Bouwfonds (no details published) and three external cost databases ((AgentschapNL, 2010b), (AgentschapNL, 2011), (SenterNovem, 2008) and (Van Eck, 2010)).
(a) The construction costs include material, labour, subcontractors and the general costs of the contractor. The construction costs exclude the general costs of the developer, value added tax, legal charges and fees of the installation consultant.
(b) The heat pump itself costs 5.000 euro and requires maintenance and replacement. The ground heat exchanger and infrastructure cost 5.000 euro and do not require maintenance or replacement.

J Historical energy prices

Table 11: historical variable energy prices (www.cbs.nl, 19-07-2011).

	natural gas [euro per 2000 m^3]		electricity [euro per 3000 kWh]	
year	price	continuous growth rate(2)	price	continuous growth rate(2)
1997	244		104	
1997 ½	254	0,040	105	0,010
1998	258	0,016	105	0,000
1998 ½	245	-0,052	105	0,000
1999	253	0,032	113	0,073
1999 ½	243	-0,040	113	0,000
2000	275	0,124	126	0,109
2000 ½	283	0,029	131	0,039
2001	358	0,235	162	0,212
2001 ½	371	0,036	159	-0,019
2002	387	0,042	157	-0,013
2002 ½	386	-0,003	160	0,019
2003	418	0,080	163	0,019
2003 ½	431	0,031	165	0,012
2004	434	0,007	170	0,030
2004 ½	438	0,009	171	0,006
2005	499	0,130	184	0,073
2005 ½	503	0,008	184	0,000
2006	552	0,093	194	0,053
2006 ½	557	0,009	197	0,015
2007	597	0,069	213	0,078
2007 ½	565	-0,055	212	-0,005
2008	576	0,019	213	0,005
2008 ½	622	0,077	218	0,023
2009	668	0,071	269	0,210
2009 ½	515	-0,260	264	-0,019
2010	518	0,006	250	-0,054
2010 ½	549	0,058	250	0,000
2011	546	-0,005	252	0,0080
range		0,495		0,267
mean		0,0288		0,0316
standard deviation		0,0821		0,0611

Notes: The price includes the costs for infrastructure, supply, transport, and the energy tax. The price excludes value added tax and refund energy tax. The price is the weighted average of the prices of the energy companies.

(2) The continuous growth rate equals $\ln(p_t/p_{t-1})$.

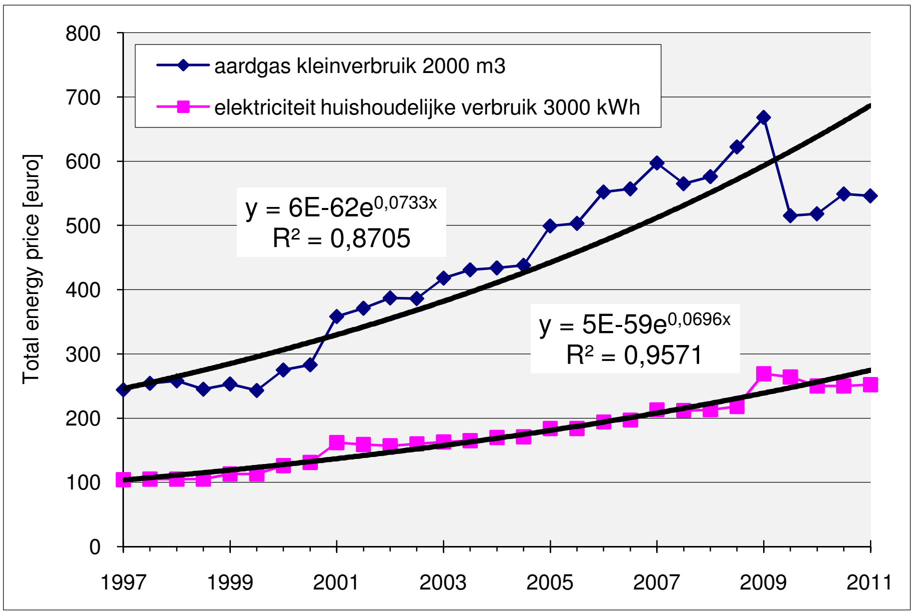

Figure 24: historical variable energy prices (www.cbs.nl, 19-07-2011).

Table 12: historical variable energy prices (www.SenterNovem.nl, 22-09-2011).

	natural gas [euro per m^3]		electricity [euro per kwh]	
year	price	continuous growth rate(2)	price	continuous growth rate(2)
2000	0,3144		0,1276	
2001	0,4413	0,339	0,1132	-0,120
2002	0,4624	0,047	0,1116	-0,014
2003	0,5002	0,079	0,1175	0,052
2004	0,5234	0,045	0,1243	0,056
2005	0,5925	0,124	0,1394	0,115
2006	0,6534	0,098	0,1501	0,074
2007	0,7174	0,093	0,1533	0,021
2008	0,7406	0,032	0,1519	-0,009
2009	0,8166	0,098	0,1681	0,101
2010	0,6370	-0,248	0,1511	-0,107
2011	0,6687	0,049	0,1504	-0,005
range		0,587		0,234
mean		0,0686		0,0149
standard deviation		0,1349		0,0766

Notes: (1) The continuous growth rate equals $\ln(p_t/p_{t-1})$.

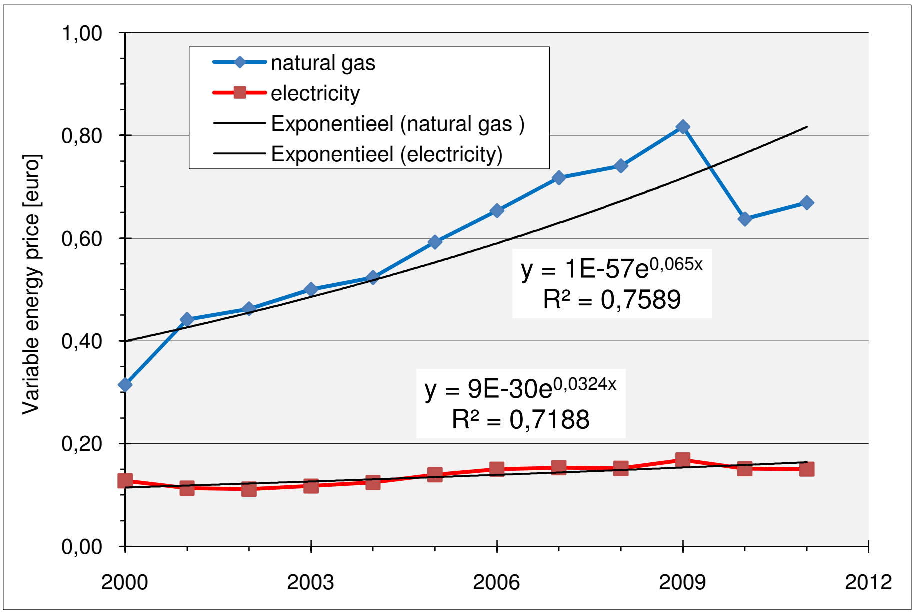

Figure 25: historical variable energy prices (www.SenterNovem.nl, 22-09-2011).

Table 11 and Table 12 contain the mean and standard deviation of the continuous growth rates of the energy prices per time interval of both data sets. These values are corrected for the length of the time interval and the average value of both data sets is used in this research.

Mean continuous growth rate:

$$\text{natural gas: } \alpha_{\text{var}} = \frac{\frac{\alpha_1}{\Delta t} + \frac{\alpha_2}{\Delta t}}{2} = \frac{\frac{0{,}0288}{0{,}5} + \frac{0{,}0686}{1{,}0}}{2} = 0{,}0631(7\% \text{ per year})$$

$$\text{electricity: } \alpha_{\text{var}} = \frac{\frac{0{,}0316}{0{,}5} + \frac{0{,}0149}{1{,}0}}{2} = 0{,}0391(4\% \text{ per year})$$

Standard deviation continuous growth rate:

$$\text{natural gas: } \sigma_{\text{var}} = \frac{\frac{\alpha_1}{\sqrt{\Delta t}} + \frac{\alpha_2}{\sqrt{\Delta t}}}{2} = \frac{\frac{0{,}0821}{\sqrt{0{,}5}} + \frac{0{,}1349}{\sqrt{1{,}0}}}{2} = 0{,}1255(13\% \text{ per year})$$

$$\text{electricity: } \sigma_{\text{var}} == \frac{\frac{0{,}0611}{\sqrt{0{,}5}} + \frac{0{,}0766}{\sqrt{1{,}0}}}{2} = 0{,}0815(9\% \text{ per year})$$

K Energy consumption reference energy concept

The following pages contain the inputs and outputs of the software program EPW – NPR 5129 (version 2.2) used to determine the dwelling-related energy consumption of the reference energy concept and the main energy saving measures. Table 13 shows the dwelling-related as well as the user-related energy consumption of the reference energy concept and the main energy saving measures.

Table 13: energy consumption of reference energy concept.

	reference	+ PV-system	+ heat pump	+ solar boiler
Primary energy [MJ]:				
space heating[a]	15587 A	15587 A	8036 E	15587 A
auxiliary space heating	2917 E	2917 E	0	2917 E
warm tap water	9761 A	9761 A	8297 E	2995 A
ventilation[a]	864 E	864 E	864 E	864 E
lighting	7012 E	7012 E	7012 E	7012 E
summer comfort	1592 E	1592 E	478 E	1592 E
comp. PV-system[b]	0	-21073 E	0	0
appliance & cooking[c]	23537 E	23537 E	23537 E	23537 E
Energy performance coefficient:				
Total [MJ]	37733	16660	24687	30967
Norm [MJ]	62685	62685	62685	62685
EPC	0,60	0,27	0,39	0,49
Energy extracted from public utility network:				
natural gas [m^3][d]	720	720	0 (-720)	528 (-192)
electricity [kWh][e]	3892	1609 (-2283)	5225 (1333)	3892

Notes: With respect to the EPC method is the energy consumption related to moistening and combined heat and power generators omitted because these items are zero in this research.

(a) With respect to the EPC method is the energy consumption related to space heating and ventilation adjusted for the quality certificate of the natural ventilation system.

(b) With respect to the EPC method is the energy yield related to the PV-panels adjusted because the EPC method incorporates an unrealistic constraint.

(c) With respect to the EPC method is the electricity consumption due to domestic appliances and cooking added. This electricity consumption is based on the size and behaviour of an average Dutch household.

(d) The natural gas extracted from the public utility network is determined by dividing the primary energy consumption allocated to natural gas (A) by the energetic upper value of natural gas (i.e. 35,2 MJ/m^3).

(e) The electricity extracted from the public utility network is determined by dividing the primary energy consumption allocated to electricity (E) by the average generation efficiency and energetic value of electricity (i.e. 39 percent and 3,6 MJ/kWh).

ALGEMENE GEGEVENS

Projectomschrijving : Onderzoek energiesystemen nieuwbouwwoningen
Bestandsnaam : \\RVWNLFS002\Users3$\wbcann\documenten Koen\definitieve epw bestanden\definitief ref hoekwoning\basis niveau.epw
Omschrijving bouwwerk : Ref hoekwoning - basis niveau
Adres :

Soort bouwwerk : Woonfunctie
Overige gebouwgegevens :
EPC-eis : 0,60

INDELING GEBOUW

Type	*Omschrijving zone*	*Ag [m²]*
Verwarmd	begane grond	46,20
Verwarmd	verdieping	45,50
Verwarmd	zolder	32,60
		------------- +
totaal		124,30

BOUWKUNDIGE GEGEVENS - TRANSMISSIE

Definitie scheidingsconstructies zone: begane grond

constructie	*begrenzing*	*constructiedeel*	*A [m²]*	*Hkr [m]*	*Rc [m²K/W]*	*U [W/m²K]*	*ZTA [-]*	*helling [°]*	*zon-wering*	*beschaduwing*
voorgevel	buiten, N	metselwerk	8,6		4,00	0,24				
		ramen	2,9			1,50	0,60	90	nee	minimale belemmering
		deur	2,4			2,00	0,00	90	nee	minimale belemmering
achtergevel	buiten, Z	metselwerk	4,2		4,00	0,24				
		ramen	9,7			1,50	0,60	90	ja	minimale belemmering
zijgevel	buiten, O	metselwerk	23,6		4,00	0,24				
		ramen	0,8			1,50	0,60	90	nee	minimale belemmering
begane grondvloer	kruip	begane grondvloer	46,2	0,50	4,00	0,11				
			----------	+						
Totaal			98,4							

Definitie scheidingsconstructies zone: verdieping

constructie	*begrenzing*	*constructiedeel*	*A [m²]*	*Hkr [m]*	*Rc [m²K/W]*	*U [W/m²K]*	*ZTA [-]*	*helling [°]*	*zon-wering*	*beschaduwing*
voorgevel	buiten, N	metselwerk	12,2		4,00	0,24				
		ramen	5,1			1,50	0,60	90	nee	minimale belemmering
achtergevel	buiten, Z	metselwerk	12,2		4,00	0,24				
		ramen	5,1			1,50	0,60	90	ja	minimale belemmering
zijgevel	buiten, O	metselwerk	25,1		4,00	0,24				
		raam	0,4			1,50	0,60	90	nee	minimale belemmering
			----------	+						
Totaal			60,1							

BOUWKUNDIGE GEGEVENS - TRANSMISSIE (vervolg)

Definitie scheidingsconstructies zone: zolder

constructie	*begrenzing*	*constructiedeel*	*A [m^2]*	*Hkr [m]*	*Rc [m^2K/W]*	*U [W/m^2K]*	*ZTA [-]*	*helling [°]*	*zonwering*	*beschaduwing*
voorgevel	buiten, boven	dak	29,7		5,00	0,19				
		dakraam	1,4			1,50	0,60	43	nee	minimale belemmering
achtergevel	buiten, boven	dak	31,1		5,00	0,19				
zijgevel	buiten, O	metselwerk	23,2		4,00	0,24				
			----------	+						
Totaal			85,4							

BOUWKUNDIGE GEGEVENS - LINEAIRE KOUDEBRUGGEN

Er is gerekend volgens de uitgebreide methode m.b.t. de koudebruggen.

Definitie lineaire koudebruggen zone: begane grond

constructie	*begrenzing*	*koudebrug*	*l / P [m]*	*type detail*	*Psi [W/mK]*	*Psi;gr [W/mK]*	*Psi;e [W/mK]*	*Eps [m^2/m]*
voorgevel	buiten, N	kozijnen onder	1,70	(eigen waarde)	0,085			
		kozijnen zij	7,70	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	2,90	(eigen waarde)	0,100			
		hoek gevel	2,70	(eigen waarde)	0,083			
achtergevel	buiten, Z	kozijnen zij	4,80	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	4,00	(eigen waarde)	0,100			
		hoek gevel	2,70	(eigen waarde)	0,083			
zijgevel	buiten, O	kozijnen onder	2,00	(eigen waarde)	0,085			
		kozijnen zij	0,80	(eigen waarde)	0,070			
		kozijnen boven	2,00	(eigen waarde)	0,075			
begane grondvloer	kruip	vloer-kozijn	5,20			-0,145	0,900	0,0012
		vloer-metselwerk dwarsgev	5,00			-0,117	0,598	0,0012
		vloer-metselwerk langsgev	8,90			-0,121	0,810	0,0012

Definitie lineaire koudebruggen zone: verdieping

constructie	*begrenzing*	*koudebrug*	*l / P [m]*	*type detail*	*Psi [W/mK]*	*Psi;gr [W/mK]*	*Psi;e [W/mK]*	*Eps [m^2/m]*
voorgevel	buiten, N	kozijnen onder	3,40	(eigen waarde)	0,085			
		kozijnen zij	6,00	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	3,40	(eigen waarde)	0,100			
		hoek gevel	3,40	(eigen waarde)	0,083			
achtergevel	buiten, Z	kozijnen onder	3,40	(eigen waarde)	0,085			
		kozijnen zij	6,00	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	3,40	(eigen waarde)	0,100			
		hoek gevel	3,40	(eigen waarde)	0,083			
zijgevel	buiten, O	kozijnen onder	0,40	(eigen waarde)	0,085			

constructie	*begrenzing*	*koudebrug*	*l / P* *[m]*	*type detail*	*Psi* *[W/mK]*	*Psi;gr* *[W/mK]*	*Psi;e* *[W/mK]*	*Eps* *[m²/m]*
		kozijnen zij	2,00	(eigen waarde)	0,070			
		kozijnen boven	0,40	(eigen waarde)	0,075			

Definitie lineaire koudebruggen zone: zolder

constructie	*begrenzing*	*koudebrug*	*l / P* *[m]*	*type detail*	*Psi* *[W/mK]*	*Psi;gr* *[W/mK]*	*Psi;e* *[W/mK]*	*Eps* *[m²/m]*
voorgevel	buiten, boven	dak-voorgevel	5,10	(eigen waarde)	-0,009			
		dak-buren	3,00	(eigen waarde)	0,186			
		dak-zijgevel	6,10	(eigen waarde)	0,191			
		nok	5,10	(eigen waarde)	0,013			
		dakraam zij	2,80	(eigen waarde)	0,088			
		dakraam onder	1,00	(eigen waarde)	0,084			
		dakraam boven	1,00	(eigen waarde)	0,065			
achtergevel	buiten, boven	dak-achtergevel	5,10	(eigen waarde)	-0,009			
		dak-buren	3,00	(eigen waarde)	0,186			
		dak-zijgevel	6,10	(eigen waarde)	0,191			

BOUWKUNDIGE GEGEVENS - INFILTRATIE

qv10;kar/m² van de woonfunctie:	0,625	[dm³/sm²]

BOUWKUNDIGE GEGEVENS - THERMISCHE CAPACITEIT

bouwtype van de woonfunctie:	traditioneel, gemengd zwaar

INSTALLATIE W - VERWARMING EN HULPENERGIE

Verwarmingssysteem 1 - Verwarming 1

verwarmingstoestel	type toestel	:	individueel centraal verwarmingstoestel
	type luchtverwarmer/ketel	:	HR-107 Ketel
	aanvoertemperatuur	:	laag temperatuursysteem (LT)
installatiekenmerken	individuele bemetering	:	ja
	installatie voorzien van buffervat	:	nee
	type verwarmingslichaam	:	vloer- en/of wandverwarming
	opwekkingsrendement (Nopw;verw)	:	0,975 [-]
	systeemrendement (Nsys;verw)	:	1,000 [-]
hulpenergie	aantal ketels-cv/luchtverwarmers met waakvlam	:	0
	gasketels-cv	:	voorzien van ventilator
		:	voorzien van elektronica
		:	circulatiepomp voorzien van pompregeling
	warmtepomp	:	geen circulatiepomp aanwezig
	individuele warmtepomp	:	geen parallel buffervat aanwezig
	gebouwgebonden warmte-kracht	:	lengte circulatieleiding 0,00 km
aangewezen zones:	begane grond		
	verdieping		
	zolder		

INSTALLATIE W - WARMTAPWATER

nr.	*opwekkingstoestel*	*klasse*	*Nopw;tap*	*qv;wp*	*aantal*	*aantal*	*Lbadr*	*Laanr*	*Lcirc*	*d;inw*	*Qbeh;tap;bruto*
			[-]	*[dm³/s]*	*badr*	*aanr*	*[m]*	*[m]*	*[m]*	*[mm]*	*[MJ]*
1	kwaliteitsverklaring (0,850)	-	0,850	0,00	1	1	5,9	9,2	0,0	<= 10	11035

nr.	*opwekkingstoestel*	*douche wtw aanwezig*	*aangesloten op*	*Ndwtw;tap*	*Qdwtw;tap*
				[-]	*[MJ]*
1	kwaliteitsverklaring (0,850)	ja	koude poort douche-mengkraan en inlaat toestel	0,600	2739

INSTALLATIE W - VENTILATIE

Ventilatiesysteem 1 - Ventilatie 1

ventilatievoorziening : zelfregelende roosters
type warmteterugwinning : geen warmteterugwinning
type voorverwarming : geen voorverwarming
aangewezen zones : begane grond
verdieping
zolder

INSTALLATIE W - VENTILATOREN

ventilatiesysteem	*type ventilator*
Ventilatiesysteem 1 - Ventilatie 1	mechanische afzuiging, gelijkstroom

INSTALLATIE W - KOELING

koelsysteem:
type toestel : geen koelmachine aanwezig
vrije koeling : nee
opwekkingsrendement voor koeling (Nopw;koel) : 0,000 [-]
systeemrendement voor koeling (Nsys;koel) : 0,000 [-]

INSTALLATIE E - VERLICHTING

omschrijving zone	*Ag [m²]*	*Qprim;vl [MJ]*
begane grond	46,2	2606
verdieping	45,5	2567
zolder	32,6	1839
	------------ +	------------ +
totaal	124,3	7012

RESULTATEN - INFORMATIEF

CO2-emissie ??

Risico te hoge temperaturen [TOjuli]

Omschrijving zone	*TOjuli*	
begane grond	0,99	(laag - matig risico)
verdieping	1,72	(laag - matig risico)
zolder	0,22	(laag - matig risico)

RESULTATEN - ENERGIEPRESTATIEGEGEVENS

verwarming	Qprim;verw	21574 MJ	Ag;verw	[m2]	124,30
hulpenergie	Qprim;hulp;verw	2917 MJ	Averlies	[m2]	230,04
warmtapwater	Qprim;tap	9761 MJ			
ventilatoren	Qprim;vent	2754 MJ	EPschil;warmte	[MJ/m2]	179,23
verlichting	Qprim;vl	7012 MJ	EPschil;koude	[MJ/m2]	14,98
zomercomfort	Qzom;comf	1592 MJ			
koeling	Qprim;koel	0 MJ	EPC-eis	[-]	0,60
bevochtiging	Qprim;bev	0 MJ	EPC	[-]	0,73
comp. PV-cellen	Qprim;pv	0 MJ	Epc voldoet niet		
comp. WK	Qprim;comp;WK	0 MJ			
		----------------- +			
totaal	Qpres;tot	45610 MJ			
	Qpres;toel	37613 MJ			

Qpres;totaal /	((330 *	Ag;verw	+ 65 *	Averlies	) *	Cepc	) =	EPC	
45610		124,3		230,0		1,12		0,73	Epc voldoet niet aan EPC-eis Bouwbesluit 1 januari 2011

RESULTATEN - AANDACHTSPUNTEN

Kwaliteitsverklaring voor toestel voor warmtapwater benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

Kwaliteitsverklaring voor toestel voor douchewater-warmteterugwinnng benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

RESULTATEN - GELIJKWAARDIGHEIDSVERKLARINGEN

Geen gelijkwaardigheidsverklaringen

ALGEMENE GEGEVENS

Projectomschrijving	:	Onderzoek energiesystemen nieuwbouwwoningen
Bestandsnaam	:	\\RVWNLFS002\Users3$\wbcann\documenten Koen\definitieve epw bestanden\definitief ref hoekwoning\basis niveau + PV.epw
Omschrijving bouwwerk	:	Ref hoekwoning - basisniveau + PV
Adres	:	
Soort bouwwerk	:	Woonfunctie
Overige gebouwgegevens	:	
EPC-eis	:	0,60

INDELING GEBOUW

Type	*Omschrijving zone*	*Ag [m²]*
Verwarmd	begane grond	46,20
Verwarmd	verdieping	45,50
Verwarmd	zolder	32,60
		------------- +
totaal		124,30

BOUWKUNDIGE GEGEVENS - TRANSMISSIE

Definitie scheidingsconstructies zone: begane grond

constructie	*begrenzing*	*constructiedeel*	*A [m²]*	*Hkr [m]*	*Rc [m²K/W]*	*U [W/m²K]*	*ZTA [-]*	*helling [°]*	*zon-wering*	*beschaduwing*
voorgevel	buiten, N	metselwerk	8,6		4,00	0,24				
		ramen	2,9			1,50	0,60	90	nee	minimale belemmering
		deur	2,4			2,00	0,00	90	nee	minimale belemmering
achtergevel	buiten, Z	metselwerk	4,2		4,00	0,24				
		ramen	9,7			1,50	0,60	90	ja	minimale belemmering
zijgevel	buiten, O	metselwerk	23,6		4,00	0,24				
		ramen	0,8			1,50	0,60	90	nee	minimale belemmering
begane grondvloer	kruip	begane grondvloer	46,2	0,50	4,00	0,11				
			----------	+						
Totaal			98,4							

Definitie scheidingsconstructies zone: verdieping

constructie	*begrenzing*	*constructiedeel*	*A [m²]*	*Hkr [m]*	*Rc [m²K/W]*	*U [W/m²K]*	*ZTA [-]*	*helling [°]*	*zon-wering*	*beschaduwing*
voorgevel	buiten, N	metselwerk	12,2		4,00	0,24				
		ramen	5,1			1,50	0,60	90	nee	minimale belemmering
achtergevel	buiten, Z	metselwerk	12,2		4,00	0,24				
		ramen	5,1			1,50	0,60	90	ja	minimale belemmering
zijgevel	buiten, O	metselwerk	25,1		4,00	0,24				
		raam	0,4			1,50	0,60	90	nee	minimale belemmering
			----------	+						
Totaal			60,1							

BOUWKUNDIGE GEGEVENS - TRANSMISSIE (vervolg)

Definitie scheidingsconstructies zone: zolder

constructie	*begrenzing*	*constructiedeel*	*A* [m²]	*Hkr* [m]	*Rc* [m²K/W]	*U* [W/m²K]	*ZTA* [-]	*helling* [°]	*zon-wering*	*beschaduwing*
voorgevel	buiten, boven	dak	29,7		5,00	0,19				
		dakraam	1,4			1,50	0,60	43	nee	minimale belemmering
achtergevel	buiten, boven	dak	31,1		5,00	0,19				
zijgevel	buiten, O	metselwerk	23,2		4,00	0,24				
			----------	+						
Totaal			85,4							

BOUWKUNDIGE GEGEVENS - LINEAIRE KOUDEBRUGGEN

Er is gerekend volgens de uitgebreide methode m.b.t. de koudebruggen.

Definitie lineaire koudebruggen zone: begane grond

constructie	*begrenzing*	*koudebrug*	*l / P* [m]	*type detail*	*Psi* [W/mK]	*Psi;gr* [W/mK]	*Psi;e* [W/mK]	*Eps* [m²/m]
voorgevel	buiten, N	kozijnen onder	1,70	(eigen waarde)	0,085			
		kozijnen zij	7,70	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	2,90	(eigen waarde)	0,100			
		hoek gevel	2,70	(eigen waarde)	0,083			
achtergevel	buiten, Z	kozijnen zij	4,80	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	4,00	(eigen waarde)	0,100			
		hoek gevel	2,70	(eigen waarde)	0,083			
zijgevel	buiten, O	kozijnen onder	2,00	(eigen waarde)	0,085			
		kozijnen zij	0,80	(eigen waarde)	0,070			
		kozijnen boven	2,00	(eigen waarde)	0,075			
begane grondvloer	kruip	vloer-kozijn	5,20			-0,145	0,900	0,0012
		vloer-metselwerk dwarsgev	5,00			-0,117	0,598	0,0012
		vloer-metselwerk langsgev	8,90			-0,121	0,810	0,0012

Definitie lineaire koudebruggen zone: verdieping

constructie	*begrenzing*	*koudebrug*	*l / P* [m]	*type detail*	*Psi* [W/mK]	*Psi;gr* [W/mK]	*Psi;e* [W/mK]	*Eps* [m²/m]
voorgevel	buiten, N	kozijnen onder	3,40	(eigen waarde)	0,085			
		kozijnen zij	6,00	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	3,40	(eigen waarde)	0,100			
		hoek gevel	3,40	(eigen waarde)	0,083			
achtergevel	buiten, Z	kozijnen onder	3,40	(eigen waarde)	0,085			
		kozijnen zij	6,00	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	3,40	(eigen waarde)	0,100			
		hoek gevel	3,40	(eigen waarde)	0,083			
zijgevel	buiten, O	kozijnen onder	0,40	(eigen waarde)	0,085			

constructie	*begrenzing*	*koudebrug*	*l / P*	*type detail*	*Psi*	*Psi;gr*	*Psi;e*	*Eps*
			[m]		*[W/mK]*	*[W/mK]*	*[W/mK]*	*[m²/m]*
		kozijnen zij	2,00	(eigen waarde)	0,070			
		kozijnen boven	0,40	(eigen waarde)	0,075			

Definitie lineaire koudebruggen zone: zolder

constructie	*begrenzing*	*koudebrug*	*l / P*	*type detail*	*Psi*	*Psi;gr*	*Psi;e*	*Eps*
			[m]		*[W/mK]*	*[W/mK]*	*[W/mK]*	*[m²/m]*
voorgevel	buiten, boven	dak-voorgevel	5,10	(eigen waarde)	-0,009			
		dak-buren	3,00	(eigen waarde)	0,186			
		dak-zijgevel	6,10	(eigen waarde)	0,191			
		nok	5,10	(eigen waarde)	0,013			
		dakraam zij	2,80	(eigen waarde)	0,088			
		dakraam onder	1,00	(eigen waarde)	0,084			
		dakraam boven	1,00	(eigen waarde)	0,065			
achtergevel	buiten, boven	dak-achtergevel	5,10	(eigen waarde)	-0,009			
		dak-buren	3,00	(eigen waarde)	0,186			
		dak-zijgevel	6,10	(eigen waarde)	0,191			

BOUWKUNDIGE GEGEVENS - INFILTRATIE

qv10;kar/m² van de woonfunctie:	0,625	[dm³/sm²]

BOUWKUNDIGE GEGEVENS - THERMISCHE CAPACITEIT

bouwtype van de woonfunctie:	traditioneel, gemengd zwaar

INSTALLATIE W - VERWARMING EN HULPENERGIE

Verwarmingssysteem 1 - Verwarming 1

verwarmingstoestel	type toestel	:	individueel centraal verwarmingstoestel
	type luchtverwarmer/ketel	:	HR-107 Ketel
	aanvoertemperatuur	:	laag temperatuursysteem (LT)
installatiekenmerken	individuele bemetering	:	ja
	installatie voorzien van buffervat	:	nee
	type verwarmingslichaam	:	vloer- en/of wandverwarming
	opwekkingsrendement (Nopw;verw)	:	0,975 [-]
	systeemrendement (Nsys;verw)	:	1,000 [-]
hulpenergie	aantal ketels-cv/luchtverwarmers met waakvlam	:	0
	gasketels-cv	:	voorzien van ventilator
		:	voorzien van elektronica
		:	circulatiepomp voorzien van pompregeling
	warmtepomp	:	geen circulatiepomp aanwezig
	individuele warmtepomp	:	geen parallel buffervat aanwezig
	gebouwgebonden warmte-kracht	:	lengte circulatieleiding 0,00 km
aangewezen zones:	begane grond		
	verdieping		
	zolder		

INSTALLATIE W - WARMTAPWATER

nr.	*opwekkingstoestel*	*klasse*	*Nopw;tap* [-]	*qv;wp* [dm³/s]	*aantal* badr	*aantal* aanr	*Lbadr* [m]	*Laanr* [m]	*Lcirc* [m]	*d;inw* [mm]	*Qbeh;tap;bruto* [MJ]
1	kwaliteitsverklaring (0,850)	-	0,850	0,00	1	1	5,9	9,2	0,0	<= 10	11035

nr.	*opwekkingstoestel*	*douche wtw aanwezig*	*aangesloten op*	*Ndwtw;tap* [-]	*Qdwtw;tap* [MJ]
1	kwaliteitsverklaring (0,850)	ja	koude poort douche-mengkraan en inlaat toestel	0,600	2739

INSTALLATIE W - VENTILATIE

Ventilatiesysteem 1 - Ventilatie 1

ventilatievoorziening : zelfregelende roosters

type warmteterugwinning : geen warmteterugwinning

type voorverwarming : geen voorverwarming

aangewezen zones : begane grond
verdieping
zolder

INSTALLATIE W - VENTILATOREN

ventilatiesysteem	*type ventilator*
Ventilatiesysteem 1 - Ventilatie 1	mechanische afzuiging, gelijkstroom

INSTALLATIE W - FOTOVOLTAISCHE SYSTEMEN

type systeem	*RFpv* [-]	*orientatie*	*helling* [°]	*Apv* [m²]	*Spv* [Wp/m²]	*beschaduwing*
centraal,vrij	0,700	Z	43	19,60	150,00	minimale belemmering

INSTALLATIE W - KOELING

koelsysteem:

type toestel : geen koelmachine aanwezig

vrije koeling : nee

opwekkingsrendement voor koeling (Nopw;koel) : 0,000 [-]

systeemrendement voor koeling (Nsys;koel) : 0,000 [-]

INSTALLATIE E - VERLICHTING

omschrijving zone	*Ag [m²]*	*Qprim;vl [MJ]*
begane grond	46,2	2606
verdieping	45,5	2567
zolder	32,6	1839
	------------ +	------------ +
totaal	124,3	7012

RESULTATEN - INFORMATIEF

CO2-emissie	??	

Risico te hoge temperaturen [TOjuli]

Omschrijving zone	*TOjuli*	
begane grond	0,99	(laag - matig risico)
verdieping	1,72	(laag - matig risico)
zolder	0,22	(laag - matig risico)

RESULTATEN - ENERGIEPRESTATIEGEGEVENS

verwarming	Qprim;verw	21574 MJ	Ag;verw	[m2]	124,30
hulpenergie	Qprim;hulp;verw	2917 MJ	Averlies	[m2]	230,04
warmtapwater	Qprim;tap	9761 MJ			
ventilatoren	Qprim;vent	2754 MJ	EPschil;warmte	[MJ/m2]	179,23
verlichting	Qprim;vl	7012 MJ	EPschil;koude	[MJ/m2]	14,98
zomercomfort	Qzom;comf	1592 MJ			
koeling	Qprim;koel	0 MJ	EPC-eis	[-]	0,60
bevochtiging	Qprim;bev	0 MJ	EPC	[-]	0,53
comp. PV-cellen	Qprim;pv	-12683 MJ	Epc voldoet		
comp. WK	Qprim;comp;WK	0 MJ			
		----------------- +			
totaal	Qpres;tot	32927 MJ			
	Qpres;toel	37613 MJ			

Qpres;totaal	/	((330 *	Ag;verw	+ 65 *	Averlies	) *	Cepc	) =	EPC	
32927			124,3		230,0		1,12		0,53	Epc voldoet aan EPC-eis Bouwbesluit 1 januari 2011

RESULTATEN - AANDACHTSPUNTEN

Kwaliteitsverklaring voor toestel voor warmtapwater benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

Kwaliteitsverklaring voor toestel voor douchewater-warmteterugwinnng benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

RESULTATEN - GELIJKWAARDIGHEIDSVERKLARINGEN

Geen gelijkwaardigheidsverklaringen

ALGEMENE GEGEVENS

Projectomschrijving	:	Onderzoek energiesystemen nieuwbouwwoningen
Bestandsnaam	:	\\RVWNLFS002\Users3$\wbcann\documenten Koen\definitieve epw bestanden\definitief ref hoekwoning\basis niveau + WP.epw
Omschrijving bouwwerk	:	Ref hoekwoning - basisniveau + WP
Adres	:	
Soort bouwwerk	:	Woonfunctie
Overige gebouwgegevens	:	
EPC-eis	:	0,60

INDELING GEBOUW

Type	*Omschrijving zone*	*Ag [m²]*	
Verwarmd	begane grond	46,20	
Verwarmd	verdieping	45,50	
Verwarmd	zolder	32,60	
		-------------	+
totaal		124,30	

BOUWKUNDIGE GEGEVENS - TRANSMISSIE

Definitie scheidingsconstructies zone: begane grond

constructie	*begrenzing*	*constructiedeel*	*A [m²]*	*Hkr [m]*	*Rc [m²K/W]*	*U [W/m²K]*	*ZTA [-]*	*helling [°]*	*zon-wering*	*beschaduwing*
voorgevel	buiten, N	metselwerk	8,6		4,00	0,24				
		ramen	2,9			1,50	0,60	90	nee	minimale belemmering
		deur	2,4			2,00	0,00	90	nee	minimale belemmering
achtergevel	buiten, Z	metselwerk	4,2		4,00	0,24				
		ramen	9,7			1,50	0,60	90	ja	minimale belemmering
zijgevel	buiten, O	metselwerk	23,6		4,00	0,24				
		ramen	0,8			1,50	0,60	90	nee	minimale belemmering
begane grondvloer	kruip	begane grondvloer	46,2	0,50	4,00	0,11				
			----------	+						
Totaal			98,4							

Definitie scheidingsconstructies zone: verdieping

constructie	*begrenzing*	*constructiedeel*	*A [m²]*	*Hkr [m]*	*Rc [m²K/W]*	*U [W/m²K]*	*ZTA [-]*	*helling [°]*	*zon-wering*	*beschaduwing*
voorgevel	buiten, N	metselwerk	12,2		4,00	0,24				
		ramen	5,1			1,50	0,60	90	nee	minimale belemmering
achtergevel	buiten, Z	metselwerk	12,2		4,00	0,24				
		ramen	5,1			1,50	0,60	90	ja	minimale belemmering
zijgevel	buiten, O	metselwerk	25,1		4,00	0,24				
		raam	0,4			1,50	0,60	90	nee	minimale belemmering
			----------	+						
Totaal			60,1							

BOUWKUNDIGE GEGEVENS - TRANSMISSIE (vervolg)

Definitie scheidingsconstructies zone: zolder

constructie	*begrenzing*	*constructiedeel*	*A*	*Hkr*	*Rc*	*U*	*ZTA*	*helling*	*zon-*	*beschaduwing*
			[m²]	*[m]*	*[m²K/W]*	*[W/m²K]*	*[-]*	*[°]*	*wering*	
voorgevel	buiten, boven	dak	29,7		5,00	0,19				
		dakraam	1,4			1,50	0,60	43	nee	minimale belemmering
achtergevel	buiten, boven	dak	31,1		5,00	0,19				
zijgevel	buiten, O	metselwerk	23,2		4,00	0,24				
			----------	+						
Totaal			85,4							

BOUWKUNDIGE GEGEVENS - LINEAIRE KOUDEBRUGGEN

Er is gerekend volgens de uitgebreide methode m.b.t. de koudebruggen.

Definitie lineaire koudebruggen zone: begane grond

constructie	*begrenzing*	*koudebrug*	*l / P*	*type detail*	*Psi*	*Psi;gr*	*Psi;e*	*Eps*
			[m]		*[W/mK]*	*[W/mK]*	*[W/mK]*	*[m²/m]*
voorgevel	buiten, N	kozijnen onder	1,70	(eigen waarde)	0,085			
		kozijnen zij	7,70	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	2,90	(eigen waarde)	0,100			
		hoek gevel	2,70	(eigen waarde)	0,083			
achtergevel	buiten, Z	kozijnen zij	4,80	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	4,00	(eigen waarde)	0,100			
		hoek gevel	2,70	(eigen waarde)	0,083			
zijgevel	buiten, O	kozijnen onder	2,00	(eigen waarde)	0,085			
		kozijnen zij	0,80	(eigen waarde)	0,070			
		kozijnen boven	2,00	(eigen waarde)	0,075			
begane grondvloer	kruip	vloer-kozijn	5,20			-0,145	0,900	0,0012
		vloer-metselwerk dwarsgev	5,00			-0,117	0,598	0,0012
		vloer-metselwerk langsgev	8,90			-0,121	0,810	0,0012

Definitie lineaire koudebruggen zone: verdieping

constructie	*begrenzing*	*koudebrug*	*l / P*	*type detail*	*Psi*	*Psi;gr*	*Psi;e*	*Eps*
			[m]		*[W/mK]*	*[W/mK]*	*[W/mK]*	*[m²/m]*
voorgevel	buiten, N	kozijnen onder	3,40	(eigen waarde)	0,085			
		kozijnen zij	6,00	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	3,40	(eigen waarde)	0,100			
		hoek gevel	3,40	(eigen waarde)	0,083			
achtergevel	buiten, Z	kozijnen onder	3,40	(eigen waarde)	0,085			
		kozijnen zij	6,00	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	3,40	(eigen waarde)	0,100			
		hoek gevel	3,40	(eigen waarde)	0,083			
zijgevel	buiten, O	kozijnen onder	0,40	(eigen waarde)	0,085			

constructie	*begrenzing*	*koudebrug*	*l / P* *[m]*	*type detail*	*Psi* *[W/mK]*	*Psi;gr* *[W/mK]*	*Psi;e* *[W/mK]*	*Eps* *[m²/m]*
		kozijnen zij	2,00	(eigen waarde)	0,070			
		kozijnen boven	0,40	(eigen waarde)	0,075			

Definitie lineaire koudebruggen zone: zolder

constructie	*begrenzing*	*koudebrug*	*l / P* *[m]*	*type detail*	*Psi* *[W/mK]*	*Psi;gr* *[W/mK]*	*Psi;e* *[W/mK]*	*Eps* *[m²/m]*
voorgevel	buiten, boven	dak-voorgevel	5,10	(eigen waarde)	-0,009			
		dak-buren	3,00	(eigen waarde)	0,186			
		dak-zijgevel	6,10	(eigen waarde)	0,191			
		nok	5,10	(eigen waarde)	0,013			
		dakraam zij	2,80	(eigen waarde)	0,088			
		dakraam onder	1,00	(eigen waarde)	0,084			
		dakraam boven	1,00	(eigen waarde)	0,065			
achtergevel	buiten, boven	dak-achtergevel	5,10	(eigen waarde)	-0,009			
		dak-buren	3,00	(eigen waarde)	0,186			
		dak-zijgevel	6,10	(eigen waarde)	0,191			

BOUWKUNDIGE GEGEVENS - INFILTRATIE

qv10;kar/m² van de woonfunctie:	0,625	[dm³/sm²]

BOUWKUNDIGE GEGEVENS - THERMISCHE CAPACITEIT

bouwtype van de woonfunctie:	traditioneel, gemengd zwaar

INSTALLATIE W - VERWARMING EN HULPENERGIE

Verwarmingssysteem 1 - Verwarming 1

verwarmingstoestel	type toestel	:	kwaliteitsverklaring
	aanvoertemperatuur	:	laag temperatuursysteem (LT)
installatiekenmerken	individuele bemetering	:	ja
	installatie voorzien van buffervat	:	ja
	type verwarmingslichaam	:	vloer- en/of wandverwarming
	opwekkingsrendement (Nopw;verw)	:	1,950 [-]
	systeemrendement (Nsys;verw)	:	0,970 [-]
hulpenergie	aantal ketels-cv/luchtverwarmers met waakvlam	:	0
	gasketels-cv	:	niet voorzien van ventilator
		:	niet voorzien van elektronica
		:	geen circulatiepomp aanwezig
	warmtepomp	:	geen circulatiepomp aanwezig
	individuele warmtepomp	:	geen parallel buffervat aanwezig
	gebouwgebonden warmte-kracht	:	lengte circulatieleiding 0,00 km
aangewezen zones:	begane grond		
	verdieping		
	zolder		

INSTALLATIE W - WARMTAPWATER

nr.	*opwekkingstoestel*	*klasse*	*Nopw;tap*	*qv;wp*	*aantal*	*aantal*	*Lbadr*	*Laanr*	*Lcirc*	*d;inw*	*Qbeh;tap;bruto*
			[-]	*[dm³/s]*	*badr*	*aanr*	*[m]*	*[m]*	*[m]*	*[mm]*	*[MJ]*
1	kwaliteitsverklaring (1,000)	-	1,000	0,00	1	1	5,9	9,2	0,0	<= 10	11035

nr.	*opwekkingstoestel*	*douche wtw aanwezig*	*aangesloten op*	*Ndwtw;tap*	*Qdwtw;tap*
				[-]	*[MJ]*
1	kwaliteitsverklaring (1,000)	ja	koude poort douche-mengkraan en inlaat toestel	0,600	2739

INSTALLATIE W - VENTILATIE

Ventilatiesysteem 1 - Ventilatie 1

ventilatievoorziening : zelfregelende roosters
type warmteterugwinning : geen warmteterugwinning
type voorverwarming : geen voorverwarming
aangewezen zones : begane grond
verdieping
zolder

INSTALLATIE W - VENTILATOREN

ventilatiesysteem	*type ventilator*
Ventilatiesysteem 1 - Ventilatie 1	mechanische afzuiging, gelijkstroom

INSTALLATIE W - KOELING

koelsysteem: type toestel : geen koelmachine aanwezig
vrije koeling : ja
opwekkingsrendement voor koeling (Nopw;koel) : 0,000 [-]
systeemrendement voor koeling (Nsys;koel) : 0,000 [-]
aangewezen zones: begane grond
verdieping
zolder

INSTALLATIE E - VERLICHTING

omschrijving zone	*Ag [m²]*		*Qprim;vl [MJ]*	
begane grond	46,2		2606	
verdieping	45,5		2567	
zolder	32,6		1839	
	------------	+	------------	+
totaal	124,3		7012	

RESULTATEN - INFORMATIEF

CO2-emissie ??

Risico te hoge temperaturen [TOjuli]

Omschrijving zone	*TOjuli*	
begane grond	0,99	(laag - matig risico)
verdieping	1,72	(laag - matig risico)
zolder	0,22	(laag - matig risico)

RESULTATEN - ENERGIEPRESTATIEGEGEVENS

verwarming	Qprim;verw	11121 MJ	Ag;verw	[m2]	124,30
hulpenergie	Qprim;hulp;verw	0 MJ	Averlies	[m2]	230,04
warmtapwater	Qprim;tap	8297 MJ			
ventilatoren	Qprim;vent	2754 MJ	EPschil;warmte	[MJ/m2]	179,23
verlichting	Qprim;vl	7012 MJ	EPschil;koude	[MJ/m2]	14,98
zomercomfort	Qzom;comf	478 MJ			
koeling	Qprim;koel	0 MJ	EPC-eis	[-]	0,60
bevochtiging	Qprim;bev	0 MJ	EPC	[-]	0,48
comp. PV-cellen	Qprim;pv	0 MJ	Epc voldoet		
comp. WK	Qprim;comp;WK	0 MJ			
		----------------- +			
totaal	Qpres;tot	29662 MJ			
	Qpres;toel	37613 MJ			

Qpres;totaal	/	((330 *	Ag;verw	+ 65 *	Averlies	) *	Cepc	) =	EPC	
29662			124,3		230,0		1,12		0,48	Epc voldoet aan EPC-eis Bouwbesluit 1 januari 2011

RESULTATEN - AANDACHTSPUNTEN

Kwaliteitsverklaring voor verwarmingstoestel benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

Kwaliteitsverklaring voor toestel voor warmtapwater benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

Kwaliteitsverklaring voor toestel voor douchewater-warmteterugwinnng benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

RESULTATEN - GELIJKWAARDIGHEIDSVERKLARINGEN

Geen gelijkwaardigheidsverklaringen

ALGEMENE GEGEVENS

Projectomschrijving	:	Onderzoek energiesystemen nieuwbouwwoningen
Bestandsnaam	:	\\RVWNLFS002\Users3$\wbcann\documenten Koen\definitieve epw bestanden\definitief ref hoekwoning\basis niveau + ZB.epw
Omschrijving bouwwerk	:	Ref hoekwoning - basisniveau + ZB
Adres	:	
Soort bouwwerk	:	Woonfunctie
Overige gebouwgegevens	:	
EPC-eis	:	0,60

INDELING GEBOUW

Type	*Omschrijving zone*	*Ag [m²]*	
Verwarmd	begane grond	46,20	
Verwarmd	verdieping	45,50	
Verwarmd	zolder	32,60	
		------------	+
totaal		124,30	

BOUWKUNDIGE GEGEVENS - TRANSMISSIE

Definitie scheidingsconstructies zone: begane grond

constructie	*begrenzing*	*constructiedeel*	*A* *[m²]*	*Hkr* *[m]*	*Rc* *[m²K/W]*	*U* *[W/m²K]*	*ZTA* *[-]*	*helling* *[°]*	*zon-* *wering*	*beschaduwing*
voorgevel	buiten, N	metselwerk	8,6		4,00	0,24				
		ramen	2,9			1,50	0,60	90	nee	minimale belemmering
		deur	2,4			2,00	0,00	90	nee	minimale belemmering
achtergevel	buiten, Z	metselwerk	4,2		4,00	0,24				
		ramen	9,7			1,50	0,60	90	ja	minimale belemmering
zijgevel	buiten, O	metselwerk	23,6		4,00	0,24				
		ramen	0,8			1,50	0,60	90	nee	minimale belemmering
begane grondvloer	kruip	begane grondvloer	46,2	0,50	4,00	0,11				
			----------	+						
Totaal			98,4							

Definitie scheidingsconstructies zone: verdieping

constructie	*begrenzing*	*constructiedeel*	*A* *[m²]*	*Hkr* *[m]*	*Rc* *[m²K/W]*	*U* *[W/m²K]*	*ZTA* *[-]*	*helling* *[°]*	*zon-* *wering*	*beschaduwing*
voorgevel	buiten, N	metselwerk	12,2		4,00	0,24				
		ramen	5,1			1,50	0,60	90	nee	minimale belemmering
achtergevel	buiten, Z	metselwerk	12,2		4,00	0,24				
		ramen	5,1			1,50	0,60	90	ja	minimale belemmering
zijgevel	buiten, O	metselwerk	25,1		4,00	0,24				
		raam	0,4			1,50	0,60	90	nee	minimale belemmering
			----------	+						
Totaal			60,1							

BOUWKUNDIGE GEGEVENS - TRANSMISSIE (vervolg)

Definitie scheidingsconstructies zone: zolder

constructie	*begrenzing*	*constructiedeel*	*A*	*Hkr*	*Rc*	*U*	*ZTA*	*helling*	*zon-*	*beschaduwing*
			[m²]	*[m]*	*[m²K/W]*	*[W/m²K]*	*[-]*	*[°]*	*wering*	
voorgevel	buiten, boven	dak	29,7		5,00	0,19				
		dakraam	1,4			1,50	0,60	43	nee	minimale belemmering
achtergevel	buiten, boven	dak	31,1		5,00	0,19				
zijgevel	buiten, O	metselwerk	23,2		4,00	0,24				
			----------	+						
Totaal			85,4							

BOUWKUNDIGE GEGEVENS - LINEAIRE KOUDEBRUGGEN

Er is gerekend volgens de uitgebreide methode m.b.t. de koudebruggen.

Definitie lineaire koudebruggen zone: begane grond

constructie	*begrenzing*	*koudebrug*	*l / P*	*type detail*	*Psi*	*Psi;gr*	*Psi;e*	*Eps*
			[m]		*[W/mK]*	*[W/mK]*	*[W/mK]*	*[m²/m]*
voorgevel	buiten, N	kozijnen onder	1,70	(eigen waarde)	0,085			
		kozijnen zij	7,70	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	2,90	(eigen waarde)	0,100			
		hoek gevel	2,70	(eigen waarde)	0,083			
achtergevel	buiten, Z	kozijnen zij	4,80	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	4,00	(eigen waarde)	0,100			
		hoek gevel	2,70	(eigen waarde)	0,083			
zijgevel	buiten, O	kozijnen onder	2,00	(eigen waarde)	0,085			
		kozijnen zij	0,80	(eigen waarde)	0,070			
		kozijnen boven	2,00	(eigen waarde)	0,075			
begane grondvloer	kruip	vloer-kozijn	5,20			-0,145	0,900	0,0012
		vloer-metselwerk dwarsgev	5,00			-0,117	0,598	0,0012
		vloer-metselwerk langsgev	8,90			-0,121	0,810	0,0012

Definitie lineaire koudebruggen zone: verdieping

constructie	*begrenzing*	*koudebrug*	*l / P*	*type detail*	*Psi*	*Psi;gr*	*Psi;e*	*Eps*
			[m]		*[W/mK]*	*[W/mK]*	*[W/mK]*	*[m²/m]*
voorgevel	buiten, N	kozijnen onder	3,40	(eigen waarde)	0,085			
		kozijnen zij	6,00	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	3,40	(eigen waarde)	0,100			
		hoek gevel	3,40	(eigen waarde)	0,083			
achtergevel	buiten, Z	kozijnen onder	3,40	(eigen waarde)	0,085			
		kozijnen zij	6,00	(eigen waarde)	0,070			
		kozijnen boven (onder vlo	3,40	(eigen waarde)	0,100			
		hoek gevel	3,40	(eigen waarde)	0,083			
zijgevel	buiten, O	kozijnen onder	0,40	(eigen waarde)	0,085			

constructie	*begrenzing*	*koudebrug*	*l / P* *[m]*	*type detail*	*Psi* *[W/mK]*	*Psi;gr* *[W/mK]*	*Psi;e* *[W/mK]*	*Eps* *[m²/m]*
		kozijnen zij	2,00	(eigen waarde)	0,070			
		kozijnen boven	0,40	(eigen waarde)	0,075			

Definitie lineaire koudebruggen zone: zolder

constructie	*begrenzing*	*koudebrug*	*l / P* *[m]*	*type detail*	*Psi* *[W/mK]*	*Psi;gr* *[W/mK]*	*Psi;e* *[W/mK]*	*Eps* *[m²/m]*
voorgevel	buiten, boven	dak-voorgevel	5,10	(eigen waarde)	-0,009			
		dak-buren	3,00	(eigen waarde)	0,186			
		dak-zijgevel	6,10	(eigen waarde)	0,191			
		nok	5,10	(eigen waarde)	0,013			
		dakraam zij	2,80	(eigen waarde)	0,088			
		dakraam onder	1,00	(eigen waarde)	0,084			
		dakraam boven	1,00	(eigen waarde)	0,065			
achtergevel	buiten, boven	dak-achtergevel	5,10	(eigen waarde)	-0,009			
		dak-buren	3,00	(eigen waarde)	0,186			
		dak-zijgevel	6,10	(eigen waarde)	0,191			

BOUWKUNDIGE GEGEVENS - INFILTRATIE

qv10;kar/m² van de woonfunctie:	0,625	[dm³/sm²]

BOUWKUNDIGE GEGEVENS - THERMISCHE CAPACITEIT

bouwtype van de woonfunctie:	traditioneel, gemengd zwaar

INSTALLATIE W - VERWARMING EN HULPENERGIE

Verwarmingssysteem 1 - Verwarming 1

verwarmingstoestel	type toestel	: individueel centraal verwarmingstoestel
	type luchtverwarmer/ketel	: HR-107 Ketel
	aanvoertemperatuur	: laag temperatuursysteem (LT)
installatiekenmerken	individuele bemetering	: ja
	installatie voorzien van buffervat	: nee
	type verwarmingslichaam	: vloer- en/of wandverwarming
	opwekkingsrendement (Nopw;verw)	: 0,975 [-]
	systeemrendement (Nsys;verw)	: 1,000 [-]
hulpenergie	aantal ketels-cv/luchtverwarmers met waakvlam	: 0
	gasketels-cv	: voorzien van ventilator
		: voorzien van elektronica
		: circulatiepomp voorzien van pompregeling
	warmtepomp	: geen circulatiepomp aanwezig
	individuele warmtepomp	: geen parallel buffervat aanwezig
	gebouwgebonden warmte-kracht	: lengte circulatieleiding 0,00 km
aangewezen zones:	begane grond	
	verdieping	
	zolder	

INSTALLATIE W - WARMTAPWATER

nr.	*opwekkingstoestel*	*klasse*	*Nopw;tap* *[-]*	*qv;wp* *[dm³/s]*	*aantal* *badr*	*aantal* *aanr*	*Lbadr* *[m]*	*Laanr* *[m]*	*Lcirc* *[m]*	*d;inw* *[mm]*	*Qbeh;tap;bruto* *[MJ]*
1	kwaliteitsverklaring (0,850)	-	0,850	0,00	1	1	5,9	9,2	0,0	<= 10	11035

nr.	*opwekkingstoestel*	*douche wtw aanwezig*	*aangesloten op*	*Ndwtw;tap* *[-]*	*Qdwtw;tap* *[MJ]*
1	kwaliteitsverklaring (0,850)	ja	koude poort douche-mengkraan en inlaat toestel	0,600	2739

INSTALLATIE W - VENTILATIE

Ventilatiesysteem 1 - Ventilatie 1

ventilatievoorziening : zelfregelende roosters
type warmteterugwinning : geen warmteterugwinning
type voorverwarming : geen voorverwarming
aangewezen zones : begane grond
verdieping
zolder

INSTALLATIE W - VENTILATOREN

ventilatiesysteem	*type ventilator*
Ventilatiesysteem 1 - Ventilatie 1	mechanische afzuiging, gelijkstroom

INSTALLATIE W - ZONNECOLLECTOREN

nr.	*warmtapwatersysteem*	*verwarmingssysteem*	*bijdrage*	*Nze;tap* *[-]*	*Nze;verw* *[-]*
1	Tapwater 1	(geen)	opwekking	-	-

nr.	*orientatie*	*helling* *[°]*	*Aze* *[m²]*	*beschaduwing*	*belemmeringen* 1	2	3	4	*overstekken* 1	2	3	4	*besch.factor*
1	Z	43	6,00	minimale belemmering	-	-	-	-	-	-	-	-	-

INSTALLATIE W - KOELING

koelsysteem: type toestel : geen koelmachine aanwezig
vrije koeling : nee
opwekkingsrendement voor koeling (Nopw;koel) : 0,000 [-]
systeemrendement voor koeling (Nsys;koel) : 0,000 [-]

INSTALLATIE E - VERLICHTING

omschrijving zone	*Ag [m²]*	*Qprim;vl [MJ]*
begane grond	46,2	2606
verdieping	45,5	2567
zolder	32,6	1839
	------------ +	------------ +
totaal	124,3	7012

RESULTATEN - INFORMATIEF

CO2-emissie	??

Risico te hoge temperaturen [TOjuli]

Omschrijving zone	*TOjuli*	
begane grond	0,99	(laag - matig risico)
verdieping	1,72	(laag - matig risico)
zolder	0,22	(laag - matig risico)

RESULTATEN - ENERGIEPRESTATIEGEGEVENS

verwarming	Qprim;verw	21574 MJ	Ag;verw	[m2]	124,30
hulpenergie	Qprim;hulp;verw	2917 MJ	Averlies	[m2]	230,04
warmtapwater	Qprim;tap	2995 MJ			
ventilatoren	Qprim;vent	2754 MJ	EPschil;warmte	[MJ/m2]	179,23
verlichting	Qprim;vl	7012 MJ	EPschil;koude	[MJ/m2]	14,98
zomercomfort	Qzom;comf	1592 MJ			
koeling	Qprim;koel	0 MJ	EPC-eis	[-]	0,60
bevochtiging	Qprim;bev	0 MJ	EPC	[-]	0,62
comp. PV-cellen	Qprim;pv	0 MJ	Epc voldoet niet		
comp. WK	Qprim;comp;WK	0 MJ			
		----------------- +			
totaal	Qpres;tot	38844 MJ			
	Qpres;toel	37613 MJ			

Qpres;totaal	/	((330 *	Ag;verw	+ 65 *	Averlies	) *	Cepc	) =	EPC	
38844			124,3		230,0		1,12		0,62	Epc voldoet niet aan EPC-eis Bouwbesluit 1 januari 2011

RESULTATEN - AANDACHTSPUNTEN

Kwaliteitsverklaring voor toestel voor warmtapwater benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

Kwaliteitsverklaring voor toestel voor douchewater-warmteterugwinnng benodigd. Afronding opwekkingsrendement naar beneden op een veelvoud van 0,025

RESULTATEN - GELIJKWAARDIGHEIDSVERKLARINGEN

Geen gelijkwaardigheidsverklaringen

L Definitive binomial option pricing models (ad chapter 6)

The following pages contain the binomial option pricing models used to determine the optimal investment timing and option value of the main energy saving measures. Table 14 contains a summary of the inputs and outputs of the binomial models.

Table 14: summary data of options on energy saving measures.

	PV-system	heat pump	solar boiler
financial parameters:			
risk-free rate of return	4%	4%	4%
risk-adjusted discount rate	7%	7%	7%
growth rate energy savings	5%	7%	7%
volatility rate energy savings	9%	13%	13%
time horizon of energy system	48 years	48 years	48 years
differential costs [€]:			
momentary investment costs	11400	10040	5700
annual variable energy costs	-502	-150	-126
annual fixed energy costs	0	-190	0
annual maintenance costs	42	0	21
annual replacement costs	211	60	105
option value [€]:			
net present value	1290	260	-1210
value of waiting	4100	2060	2440
option value	5390	2320	1230
optimal investment timing:			
practical investment threshold (epi*)	2,0	1,9	2,1
expected time until epi* [years]	16	11	13
expected payback period of first element at practical investment threshold [years]	9	13	13

Binomial model of expansion option on PV-system

Input parameters:			Intermediate parameters:		Solver:	
risk-free rate of return (r_f)	4,0%	*0,0392*	growth rate up movement ($u=\exp(\sigma*\sqrt{\Delta t})$)	1,090	net present value (V-I)	1292
discount rate (risk-adjusted) (ρ)	7,0%	*0,0677*	growth rate down movement (d=1/u)	0,917	5% of net present value	65
exp. annual growth rate energy prices (α_{var})	5,0%	*0,0488*	risk-free rate per time interval ($rdt=\exp(r_f*\Delta t)$)	1,040	value of waiting (W)	4103
exp. annual st. deviation energy prices (σ_{var})	9,0%	*0,0862*	risk neutral prob. up movement (q=(rdt-d)/(u-d))	0,710	option value (F)	5395
time horizon energy systems (T)	48	years	risk neutral prob. down movement (1-q)	0,290	cel bepalen	-4038
investment costs energy-saving measure (I)	11400	Euros	length of time intervals ($\Delta t=T/n$)	1,000		
current annual variable energy costs savings	502	Euros	Output parameters:		Optimal investment timing:	
current additional annual fixed energy costs	0	Euros	net present value (V-I)	1292	$Z = \alpha_{var} - 0,5*\sigma_{var}$^2	0,05
additional annual maintenance costs	42	Euros	value of waiting (W)	4103	expected years	0,0
additional annual replacement costs	211	Euros	option value (F)	5395		

Event tree for energy price index:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91
1		0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66
2			0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60
3				0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72
4					0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97
5						0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34
6							0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81
7								0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37
8									0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99
9										0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68
10											0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41
11												0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19
12													0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00
13														0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84
14															0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71
15																0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60
16																	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50
17																		0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42
18																			0,21	0,23	0,25	0,27	0,30	0,33	0,36
19																				0,19	0,21	0,23	0,25	0,27	0,30
20																					0,18	0,19	0,21	0,23	0,25
21																						0,16	0,18	0,19	0,21
22																							0,15	0,16	0,18
23																								0,14	0,15
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25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76	17,18	18,73	20,41	22,25	24,25	26,44	28,82	31,41	34,24	37,32	40,68	44,34	48,33	52,68	57,42	62,59
7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76	17,18	18,73	20,41	22,25	24,25	26,44	28,82	31,41	34,24	37,32	40,68	44,34	48,33	52,68
6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76	17,18	18,73	20,41	22,25	24,25	26,44	28,82	31,41	34,24	37,32	40,68	44,34
5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76	17,18	18,73	20,41	22,25	24,25	26,44	28,82	31,41	34,24	37,32
4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76	17,18	18,73	20,41	22,25	24,25	26,44	28,82	31,41
3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76	17,18	18,73	20,41	22,25	24,25	26,44
3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76	17,18	18,73	20,41	22,25
2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76	17,18	18,73
2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27	14,46	15,76
1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17	12,17	13,27
1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40	10,25	11,17
1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91	8,62	9,40
1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66	7,26	7,91
0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60	6,11	6,66
0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72	5,14	5,60
0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97	4,33	4,72
0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34	3,64	3,97
0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81	3,07	3,34
0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37	2,58	2,81
0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99	2,17	2,37
0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68	1,83	1,99
0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41	1,54	1,68
0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19	1,30	1,41
0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00	1,09	1,19
0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84	0,92	1,00
0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71	0,77	0,84
	0,11	0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60	0,65	0,71
		0,10	0,11	0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50	0,55	0,60
			0,09	0,10	0,11	0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42	0,46	0,50
				0,08	0,09	0,10	0,11	0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36	0,39	0,42
					0,08	0,08	0,09	0,10	0,11	0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30	0,33	0,36
						0,07	0,08	0,08	0,09	0,10	0,11	0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25	0,27	0,30
							0,06	0,07	0,08	0,08	0,09	0,10	0,11	0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21	0,23	0,25
								0,06	0,06	0,07	0,08	0,08	0,09	0,10	0,11	0,12	0,13	0,14	0,15	0,16	0,18	0,19	0,21
									0,05	0,06	0,06	0,07	0,08	0,08	0,09	0,10	0,11	0,12	0,13	0,14	0,15	0,16	0,18
										0,05	0,05	0,06	0,06	0,07	0,08	0,08	0,09	0,10	0,11	0,12	0,13	0,14	0,15
											0,04	0,05	0,05	0,06	0,06	0,07	0,08	0,08	0,09	0,10	0,11	0,12	0,13
												0,04	0,04	0,05	0,05	0,06	0,06	0,07	0,08	0,08	0,09	0,10	0,11
													0,04	0,04	0,04	0,05	0,05	0,06	0,06	0,07	0,08	0,08	0,09
														0,03	0,04	0,04	0,04	0,05	0,05	0,06	0,06	0,07	0,08
															0,03	0,03	0,04	0,04	0,04	0,05	0,05	0,06	0,06
																0,03	0,03	0,03	0,04	0,04	0,04	0,05	0,05
																	0,03	0,03	0,03	0,03	0,04	0,04	0,04
																		0,02	0,03	0,03	0,03	0,03	0,04
																			0,02	0,02	0,03	0,03	0,03
																				0,02	0,02	0,02	0,03
																					0,02	0,02	0,02
																						0,02	0,02
																							0,02

Capitalisation factor:

t	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	18,0	19,0	20,0	21,0	22,0	23,0	24,0
K_{var}	31,5	31,1	30,7	30,3	29,8	29,4	28,9	28,5	28,0	27,5	27,1	26,6	26,1	25,6	25,0	24,5	24,0	23,4	22,9	22,3	21,7	21,1	20,5	19,9	19,3
K_{cpi}	18,7	18,6	18,5	18,4	18,2	18,1	18,0	17,9	17,7	17,6	17,4	17,2	17,1	16,9	16,7	16,5	16,3	16,1	15,8	15,6	15,3	15,1	14,8	14,5	14,2
K_0	14,1	14,0	14,0	14,0	13,9	13,9	13,8	13,7	13,7	13,6	13,5	13,5	13,4	13,3	13,2	13,1	13,0	12,9	12,7	12,6	12,5	12,3	12,1	12,0	11,8

Event tree for value of energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	15812	17013	18296	19668	21133	22696	24362	26136	28023	30029	32158	34416	36806	39333	42000	44810	47766	50869	54118	57513	61050	64723	68526	72446	76471
1		14319	15400	16554	17787	19103	20505	21998	23587	25275	27067	28967	30979	33105	35350	37716	40204	42815	45550	48407	51384	54476	57677	60977	64364
2			12962	13933	14971	16078	17258	18515	19852	21273	22782	24381	26074	27864	29754	31745	33839	36037	38339	40744	43249	45852	48545	51323	54174
3				11727	12601	13533	14526	15584	16709	17905	19175	20521	21946	23453	25043	26719	28481	30331	32269	34293	36402	38592	40860	43197	45597
4					10606	11390	12226	13117	14064	15071	16139	17272	18472	19740	21078	22489	23972	25529	27160	28864	30639	32482	34391	36358	38378
5						9587	10291	11040	11837	12685	13584	14538	15547	16614	17741	18928	20177	21487	22860	24294	25788	27340	28946	30602	32302
6							8661	9292	9963	10676	11433	12236	13086	13984	14932	15932	16982	18086	19241	20448	21705	23011	24363	25757	27188
7								7821	8386	8986	9623	10299	11014	11770	12568	13409	14294	15222	16195	17211	18269	19368	20506	21679	22884
8									7058	7563	8100	8668	9270	9907	10578	11286	12031	12812	13631	14486	15377	16302	17260	18247	19261
9										6366	6817	7296	7803	8338	8904	9499	10126	10784	11473	12192	12942	13721	14527	15358	16211
10											5738	6141	6567	7018	7494	7995	8523	9077	9656	10262	10893	11549	12227	12927	13645
11												5169	5528	5907	6308	6730	7174	7640	8128	8637	9169	9720	10291	10880	11485
12													4652	4972	5309	5664	6038	6430	6841	7270	7717	8181	8662	9158	9666
13														4185	4468	4767	5082	5412	5758	6119	6495	6886	7291	7708	8136
14															3761	4013	4277	4555	4846	5150	5467	5796	6136	6487	6848
15																3377	3600	3834	4079	4335	4601	4878	5165	5460	5764
16																	3030	3227	3433	3649	3873	4106	4347	4596	4851
17																		2716	2890	3071	3260	3456	3659	3868	4083
18																			2432	2585	2744	2909	3080	3256	3437
19																				2175	2309	2448	2592	2740	2893
20																					1944	2061	2182	2307	2435
21																						1734	1836	1941	2049
22																							1546	1634	1725
23																								1375	1452
24																									1222
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25,0	26,0	27,0	28,0	29,0	30,0	31,0	32,0	33,0	34,0	35,0	36,0	37,0	38,0	39,0	40,0	41,0	42,0	43,0	44,0	45,0	46,0	47,0	48,0
18,6	18,0	17,3	16,6	15,9	15,2	14,5	13,8	13,0	12,3	11,5	10,7	9,9	9,1	8,3	7,4	6,5	5,7	4,8	3,8	2,9	2,0	1,0	0,0
13,9	13,5	13,2	12,8	12,4	12,0	11,6	11,1	10,6	10,1	9,6	9,1	8,5	7,9	7,3	6,6	5,9	5,2	4,4	3,6	2,8	1,9	1,0	0,0
11,6	11,3	11,1	10,9	10,6	10,3	10,0	9,7	9,3	9,0	8,6	8,1	7,7	7,2	6,7	6,1	5,5	4,9	4,2	3,5	2,7	1,9	1,0	0,0

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
80582	84755	88963	93171	97337	101410	105331	109028	112418	115401	117862	119667	120660	120658	119454	116805	112434	106021	97199	85550	70593	51780	28486	0
67824	71337	74878	78420	81926	85355	88655	91767	94620	97130	99202	100721	101557	101556	100542	98313	94634	89236	81811	72006	59416	43582	23976	0
57086	60043	63024	66005	68956	71842	74619	77238	79640	81753	83496	84775	85478	85477	84624	82748	79651	75108	68858	60606	50010	36682	20180	0
48048	50537	53046	55555	58039	60468	62805	65010	67031	68810	70277	71354	71945	71945	71227	69647	67041	63217	57957	51011	42092	30875	16985	0
40441	42536	44647	46759	48850	50894	52862	54718	56419	57916	59151	60057	60555	60554	59950	58621	56427	53208	48781	42935	35428	25986	14296	0
34039	35801	37579	39356	41116	42837	44493	46055	47486	48747	49786	50549	50968	50967	50459	49340	47493	44784	41058	36137	29819	21872	12033	0
28650	30133	31629	33125	34607	36055	37449	38763	39968	41029	41904	42546	42899	42898	42470	41528	39974	37694	34558	30416	25098	18409	10128	0
24114	25363	26622	27881	29128	30347	31520	32626	33641	34533	35270	35810	36107	36107	35746	34954	33646	31726	29087	25600	21125	15495	8524	0
20296	21347	22407	23467	24516	25542	26530	27461	28315	29066	29686	30141	30390	30390	30087	29420	28319	26703	24482	21547	17780	13042	7175	0
17083	17968	18860	19752	20635	21498	22330	23113	23832	24464	24986	25369	25579	25579	25324	24762	23835	22476	20606	18136	14965	10977	6039	0
14378	15123	15874	16625	17368	18095	18794	19454	20059	20591	21030	21352	21529	21529	21314	20842	20062	18917	17343	15265	12596	9239	5083	0
12102	12729	13361	13993	14618	15230	15819	16374	16883	17331	17701	17972	18121	18121	17940	17542	16886	15922	14598	12848	10602	7776	4278	0
10186	10713	11245	11777	12304	12819	13314	13782	14210	14587	14898	15127	15252	15252	15100	14765	14212	13402	12286	10814	8923	6545	3601	0
8573	9017	9465	9913	10356	10789	11206	11600	11960	12278	12540	12732	12837	12837	12709	12427	11962	11280	10341	9102	7511	5509	3031	0
7216	7590	7966	8343	8716	9081	9432	9763	10067	10334	10554	10716	10805	10805	10697	10460	10068	9494	8704	7661	6321	4637	2551	0
6074	6388	6705	7022	7336	7643	7939	8218	8473	8698	8883	9019	9094	9094	9003	8804	8474	7991	7326	6448	5321	3903	2147	0
5112	5377	5644	5911	6175	6433	6682	6917	7132	7321	7477	7591	7654	7654	7578	7410	7133	6726	6166	5427	4478	3285	1807	0
4303	4525	4750	4975	5197	5415	5624	5822	6003	6162	6293	6390	6443	6443	6378	6237	6003	5661	5190	4568	3769	2765	1521	0
3621	3809	3998	4187	4374	4558	4734	4900	5052	5186	5297	5378	5423	5423	5368	5249	5053	4765	4368	3845	3173	2327	1280	0
3048	3206	3365	3524	3682	3836	3984	4124	4252	4365	4458	4527	4564	4564	4519	4418	4253	4010	3677	3236	2670	1959	1078	0
2566	2698	2832	2966	3099	3229	3353	3471	3579	3674	3752	3810	3842	3841	3803	3719	3580	3375	3095	2724	2247	1649	907	0
2159	2271	2384	2497	2608	2717	2823	2922	3012	3092	3158	3207	3233	3233	3201	3130	3013	2841	2605	2292	1892	1388	763	0
1817	1912	2007	2101	2195	2287	2376	2459	2536	2603	2658	2699	2721	2721	2694	2634	2536	2391	2192	1930	1592	1168	642	0
1530	1609	1689	1769	1848	1925	2000	2070	2134	2191	2237	2272	2291	2291	2268	2217	2134	2013	1845	1624	1340	983	541	0
1288	1354	1421	1489	1555	1620	1683	1742	1796	1844	1883	1912	1928	1928	1909	1866	1796	1694	1553	1367	1128	827	455	0
1084	1140	1196	1253	1309	1364	1417	1466	1512	1552	1585	1609	1623	1623	1606	1571	1512	1426	1307	1151	949	696	383	0
	959	1007	1055	1102	1148	1192	1234	1272	1306	1334	1355	1366	1366	1352	1322	1273	1200	1100	968	799	586	322	0
		848	888	927	966	1004	1039	1071	1099	1123	1140	1150	1150	1138	1113	1071	1010	926	815	673	493	271	0
			747	781	813	845	874	901	925	945	960	968	968	958	937	902	850	779	686	566	415	228	0
				657	684	711	736	759	779	795	808	814	814	806	788	759	716	656	577	476	349	192	0
					576	598	619	639	656	670	680	685	685	679	664	639	602	552	486	401	294	162	0
						504	521	538	552	564	572	577	577	571	558	538	507	465	409	338	248	136	0
							439	452	464	474	482	486	486	481	470	452	427	391	344	284	208	115	0
								381	391	399	405	409	409	405	396	381	359	329	290	239	175	96	0
									329	336	341	344	344	341	333	321	302	277	244	201	148	81	0
										283	287	290	290	287	280	270	254	233	205	169	124	68	0
											242	244	244	241	236	227	214	196	173	143	105	58	0
												205	205	203	199	191	180	165	145	120	88	48	0
													173	171	167	161	152	139	122	101	74	41	0
														144	141	135	128	117	103	85	62	34	0
															118	114	107	99	87	72	52	29	0
																96	90	83	73	60	44	24	0
																	76	70	61	51	37	20	0
																		59	52	43	31	17	0
																			44	36	26	14	0
																				30	22	12	0
																					19	10	0
																						9	0
																							0

Total investment costs of energy-saving measure:

t	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	18,0	19,0	20,0	21,0	22,0	23,0	24,0
I(t)	14521	14480	14436	14388	14338	14284	14227	14165	14099	14028	13953	13872	13785	13693	13594	13488	13374	13253	13123	12984	12836	12677	12506	12324	12129

Event tree for value of option on energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	5395	6130	6957	7884	8923	10087	11389	12843	14467	16278	18297	20544	23020	25640	28406	31322	34392	37616	40995	44529	48214	52047	56019	60122	64342
1		4336	4951	5644	6425	7303	8289	9395	10636	12024	13577	15313	17251	19413	21756	24228	26829	29562	32427	35423	38549	41800	45170	48652	52235
2			3428	3935	4510	5159	5893	6720	7652	8700	9877	11197	12677	14333	16186	18257	20464	22784	25215	27759	30414	33175	36039	38999	42045
3				2658	3070	3539	4073	4678	5364	6140	7016	8004	9116	10366	11770	13344	15107	17078	19146	21309	23566	25916	28353	30873	33468
4					2015	2343	2720	3151	3643	4203	4840	5563	6383	7309	8356	9536	10865	12359	14037	15880	17803	19806	21884	24034	26249
5						1487	1744	2039	2380	2772	3221	3736	4323	4992	5753	6616	7595	8703	9954	11364	12952	14663	16440	18278	20173
6							1064	1259	1485	1749	2053	2406	2812	3279	3816	4429	5130	5929	6838	7870	9039	10362	11857	13433	15059
7								734	877	1045	1242	1473	1742	2055	2418	2838	3322	3880	4520	5253	6090	7044	8129	9360	10754
8									485	586	706	849	1017	1216	1449	1722	2042	2414	2847	3347	3926	4592	5357	6233	7234
9										305	373	455	553	671	811	979	1177	1411	1687	2012	2392	2835	3351	3948	4640
10											181	224	277	341	419	514	628	765	929	1125	1359	1635	1962	2347	2799
11												100	125	157	197	245	305	378	467	576	708	868	1059	1289	1564
12													51	65	82	105	133	168	211	265	332	415	517	642	794
13														23	30	39	50	65	84	107	137	175	223	283	358
14															9	12	16	22	28	37	49	64	83	107	139
15																3	4	6	8	11	14	19	25	34	45
16																	1	1	2	2	3	4	6	8	11
17																		0	0	0	1	1	1	2	2
18																			0	0	0	0	0	0	0
19																				0	0	0	0	0	0
20																					0	0	0	0	0
21																						0	0	0	0
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25,0	26,0	27,0	28,0	29,0	30,0	31,0	32,0	33,0	34,0	35,0	36,0	37,0	38,0	39,0	40,0	41,0	42,0	43,0	44,0	45,0	46,0	47,0	48,0
11921	11698	11459	11204	10930	10638	10325	9990	9632	9249	8839	8400	7930	7428	6890	6315	5699	5041	4336	3582	2775	1912	988	0

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
68661	73057	77504	81967	86406	90772	95006	99038	102786	106152	109023	111267	112729	113231	112564	110491	106735	100980	92863	81968	67817	49868	27498	0
55903	59639	63419	67216	70996	74717	78330	81777	84988	87882	90363	92322	93627	94128	93652	91998	88934	84195	77475	68423	56641	41670	22988	0
45165	48345	51564	54801	58025	61204	64294	67248	70007	72504	74658	76375	77548	78050	77734	76433	73952	70067	64522	57024	47234	34770	19192	0
36127	38839	41587	44351	47108	49830	52480	55020	57399	59561	61439	62954	64015	64517	64336	63332	61341	58176	53621	47428	39317	28962	15997	0
28520	30838	33188	35556	37920	40256	42537	44727	46787	48667	50312	51657	52625	53127	53060	52306	50728	48167	44445	39352	32653	24074	13308	0
22118	24104	26120	28153	30186	32199	34168	36064	37854	39498	40948	42149	43038	43540	43569	43025	41794	39744	36722	32555	27044	19960	11044	0
16729	18436	20170	21922	23676	25417	27124	28773	30336	31780	33065	34146	34968	35470	35580	35213	34275	32653	30222	26834	22323	16497	9139	0
12193	13665	15163	16677	18197	19709	21195	22636	24009	25285	26431	27410	28177	28679	28856	28639	27946	26686	24750	22018	18349	13583	7536	0
8375	9649	10948	12263	13586	14904	16205	17471	18683	19817	20847	21741	22460	22962	23197	23105	22619	21663	20145	17965	15005	11130	6186	0
5436	6352	7400	8548	9704	10860	12004	13123	14200	15215	16147	16969	17649	18151	18433	18447	18136	17435	16269	14554	12190	9065	5051	0
3327	3943	4657	5484	6437	7457	8469	9464	10427	11342	12192	12953	13599	14101	14424	14527	14362	13877	13007	11683	9821	7327	4094	0
1891	2278	2736	3274	3904	4639	5494	6384	7251	8082	8862	9572	10191	10693	11050	11227	11186	10882	10261	9266	7826	5864	3290	0
979	1202	1472	1795	2181	2640	3184	3825	4578	5338	6060	6727	7322	7824	8209	8450	8513	8361	7950	7232	6148	4633	2612	0
451	566	708	882	1096	1356	1671	2052	2508	3053	3701	4332	4907	5409	5819	6112	6263	6239	6005	5520	4735	3597	2042	0
179	230	295	377	481	610	771	970	1216	1518	1887	2334	2875	3377	3807	4145	4369	4453	4368	4079	3546	2725	1563	0
59	78	103	135	177	230	300	388	501	644	824	1050	1332	1682	2113	2489	2775	2950	2990	2866	2545	1991	1159	0
15	21	28	38	52	69	93	124	165	220	291	383	503	658	858	1111	1433	1685	1830	1845	1703	1373	819	0
3	4	6	8	11	15	21	29	40	55	76	104	141	193	261	353	476	639	854	986	994	853	533	0
0	1	1	1	1	2	3	4	6	9	13	18	25	36	51	72	101	143	201	283	397	415	292	0
0	0	0	0	0	0	0	0	0	1	1	1	2	3	4	6	9	13	19	28	42	61	89	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0	0	0	0	0	0	0
											0	0	0	0	0	0	0	0	0	0	0	0	0
												0	0	0	0	0	0	0	0	0	0	0	0
													0	0	0	0	0	0	0	0	0	0	0
														0	0	0	0	0	0	0	0	0	0
															0	0	0	0	0	0	0	0	0
																0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0
																		0	0	0	0	0	0
																			0	0	0	0	0
																				0	0	0	0
																					0	0	0
																						0	0
																							0

Binomial model of switch option on heat pump

Input parameters:			Intermediate parameters:		Solver:	
risk-free rate of return (r_f)	4,0%	*0,0392*	growth rate up movement (u=exp(σ*√Δt))	1,130	net present value (V-I)	255
discount rate (risk-adjusted) (ρ)	7,0%	*0,0677*	growth rate down movement (d=1/u)	0,885	5% of net present value	13
exp. annual growth rate energy prices (α_{var})	7,0%	*0,0677*	risk-free rate per time interval (rdt=exp(r_f*Δt))	1,040	value of waiting (W)	2064
exp. annual st. deviation energy prices (σ_{var})	13,0%	*0,1222*	risk neutral prob. up movement (q=(rdt-d)/(u-d))	0,633	option value (F)	2319
time horizon energy systems (T)	48	years	risk neutral prob. down movement (1-q)	0,367	cel bepalen	-2051
investment costs energy-saving measure (I)	10040	Euros	length of time intervals (Δt=T/n)	1,000		
current annual variable energy costs savings	150	Euros	Output parameters:		Optimal investment timing:	
current additional annual fixed energy costs	-190	Euros	net present value (V-I)	255	$Z = \alpha_{var} - 0,5*\sigma_{var}$^2	0,06
additional annual maintenance costs	0	Euros	value of waiting (W)	2064	expected years	0,00
additional annual replacement costs	60	Euros	option value (F)	2319		

Event tree for energy price index:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79
1		0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71
2			0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52
3				0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02
4					0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07
5						0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53
6							0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33
7								0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39
8									0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66
9										0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08
10											0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63
11												0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28
12													0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00
13														0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78
14															0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61
15																0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48
16																	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38
17																		0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29
18																			0,11	0,13	0,14	0,16	0,18	0,20	0,23
19																				0,10	0,11	0,13	0,14	0,16	0,18
20																					0,09	0,10	0,11	0,13	0,14
21																						0,08	0,09	0,10	0,11
22																							0,07	0,08	0,09
23																								0,06	0,07
24																									0,05
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21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78	150,04	169,55	191,59	216,50	244,64	276,44	312,38	352,99
16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78	150,04	169,55	191,59	216,50	244,64	276,44
13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78	150,04	169,55	191,59	216,50
10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78	150,04	169,55
7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78
6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99
4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44
3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78
3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95
2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12
1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63
1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99
1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79
0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71
0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52
0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02
0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07
0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53
0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33
0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39
0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66
0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08
0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63
0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28
0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00
0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78
	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61
		0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48
			0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38
				0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29
					0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23
						0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18
							0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14
								0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11
									0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09
										0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07
											0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05
												0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04
													0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,03	0,03	0,03	0,03
														0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03
															0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02
																0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02
																	0,01	0,01	0,01	0,01	0,01	0,01	0,01
																		0,01	0,01	0,01	0,01	0,01	0,01
																			0,00	0,01	0,01	0,01	0,01
																				0,00	0,00	0,01	0,01
																					0,00	0,00	0,00
																						0,00	0,00
																							0,00

Capitalisation factor:

t	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	18,0	19,0	20,0	21,0	22,0	23,0	24,0
K_{var}	48,0	47,0	46,0	45,0	44,0	43,0	42,0	41,0	40,0	39,0	38,0	37,0	36,0	35,0	34,0	33,0	32,0	31,0	30,0	29,0	28,0	27,0	26,0	25,0	24,0
K_{cpi}	18,7	18,6	18,5	18,4	18,2	18,1	18,0	17,9	17,7	17,6	17,4	17,2	17,1	16,9	16,7	16,5	16,3	16,1	15,8	15,6	15,3	15,1	14,8	14,5	14,2
K_0	14,1	14,0	14,0	14,0	13,9	13,9	13,8	13,7	13,7	13,6	13,5	13,5	13,4	13,3	13,2	13,1	13,0	12,9	12,7	12,6	12,5	12,3	12,1	12,0	11,8

Event tree for value of energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	7200	7967	8811	9740	10761	11884	13116	14469	15951	17574	19349	21289	23406	25715	28227	30959	33923	37135	40609	44359	48397	52735	57384	62350	67637
1		6239	6900	7628	8428	9307	10272	11331	12492	13763	15153	16672	18331	20138	22106	24245	26567	29082	31803	34739	37902	41300	44940	48829	52970
2			5404	5973	6600	7289	8044	8874	9783	10778	11867	13057	14356	15771	17312	18988	20806	22776	24906	27206	29683	32344	35195	38240	41483
3				4678	5169	5708	6300	6950	7661	8441	9294	10226	11243	12351	13558	14870	16294	17837	19505	21306	23246	25330	27563	29948	32487
4					4048	4470	4934	5442	6000	6611	7278	8008	8805	9673	10618	11645	12761	13969	15276	16686	18205	19837	21586	23454	25442
5						3501	3864	4262	4699	5177	5700	6272	6895	7575	8315	9120	9993	10940	11963	13068	14257	15535	16905	18368	19925
6							3026	3338	3680	4054	4464	4912	5400	5933	6512	7142	7826	8567	9369	10234	11165	12166	13239	14384	15604
7								2614	2882	3175	3496	3846	4229	4646	5100	5594	6129	6709	7337	8015	8744	9528	10368	11265	12220
8									2257	2487	2738	3012	3312	3639	3994	4381	4800	5255	5746	6277	6848	7462	8120	8822	9570
9										1947	2144	2359	2594	2849	3128	3431	3759	4115	4500	4916	5363	5844	6359	6909	7495
10											1679	1848	2031	2232	2450	2687	2944	3223	3524	3850	4200	4577	4980	5411	5870
11												1447	1591	1748	1918	2104	2306	2524	2760	3015	3289	3584	3900	4238	4597
12													1246	1369	1502	1648	1806	1977	2161	2361	2576	2807	3054	3319	3600
13														1072	1177	1290	1414	1548	1693	1849	2017	2198	2392	2599	2819
14															921	1011	1107	1212	1326	1448	1580	1721	1873	2035	2208
15																791	867	949	1038	1134	1237	1348	1467	1594	1729
16																	679	743	813	888	969	1056	1149	1248	1354
17																		582	637	696	759	827	900	978	1061
18																			499	545	594	648	705	766	831
19																				427	465	507	552	600	650
20																					364	397	432	470	509
21																						311	338	368	399
22																							265	288	312
23																								226	245
24																									192
25																									
26																									
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25,0	26,0	27,0	28,0	29,0	30,0	31,0	32,0	33,0	34,0	35,0	36,0	37,0	38,0	39,0	40,0	41,0	42,0	43,0	44,0	45,0	46,0	47,0	48,0
23,0	22,0	21,0	20,0	19,0	18,0	17,0	16,0	15,0	14,0	13,0	12,0	11,0	10,0	9,0	8,0	7,0	6,0	5,0	4,0	3,0	2,0	1,0	0,0
13,9	13,5	13,2	12,8	12,4	12,0	11,6	11,1	10,6	10,1	9,6	9,1	8,5	7,9	7,3	6,6	5,9	5,2	4,4	3,6	2,8	1,9	1,0	0,0
11,6	11,3	11,1	10,9	10,6	10,3	10,0	9,7	9,3	9,0	8,6	8,1	7,7	7,2	6,7	6,1	5,5	4,9	4,2	3,5	2,7	1,9	1,0	0,0

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
73245	79169	85394	91900	98655	105613	112712	119873	126990	133933	140534	146587	151840	155981	158633	159338	157545	152594	143693	129898	110089	82933	46857	0
57362	62001	66876	71972	77261	82710	88270	93878	99452	104889	110058	114799	118913	122156	124233	124785	123381	119503	112532	101729	86216	64949	36696	0
44923	48556	52374	56364	60507	64774	69129	73520	77886	82143	86192	89905	93126	95666	97292	97725	96625	93589	88129	79669	67519	50865	28739	0
35181	38026	41016	44141	47386	50728	54138	57577	60996	64330	67501	70409	72932	74921	76194	76533	75672	73294	69018	62392	52878	39834	22506	0
27552	29780	32122	34569	37110	39727	42398	45091	47769	50380	52863	55140	57116	58674	59671	59937	59262	57400	54051	48862	41411	31196	17626	0
21577	23322	25156	27073	29063	31112	33204	35313	37410	39455	41400	43183	44730	45950	46731	46939	46411	44952	42330	38266	32431	24431	13804	0
16898	18265	19701	21202	22760	24366	26003	27655	29297	30899	32422	33819	35030	35986	36598	36760	36347	35204	33151	29968	25398	19133	10810	0
13234	14304	15429	16604	17825	19082	20364	21658	22944	24198	25391	26485	27434	28182	28661	28789	28465	27570	25962	23470	19890	14984	8466	0
10364	11202	12083	13004	13959	14944	15948	16962	17969	18951	19885	20742	21485	22071	22446	22546	22292	21591	20332	18380	15577	11735	6630	0
8116	8773	9463	10184	10932	11703	12490	13283	14072	14841	15573	16244	16826	17285	17578	17657	17458	16909	15923	14394	12199	9190	5192	0
6356	6870	7411	7975	8562	9165	9781	10403	11021	11623	12196	12721	13177	13536	13767	13828	13672	13242	12470	11273	9554	7197	4066	0
4978	5381	5804	6246	6705	7178	7660	8147	8631	9102	9551	9963	10320	10601	10781	10829	10707	10371	9766	8828	7482	5636	3185	0
3899	4214	4545	4891	5251	5621	5999	6380	6759	7129	7480	7802	8082	8302	8443	8481	8385	8122	7648	6914	5859	4414	2494	0
3053	3300	3560	3831	4112	4402	4698	4997	5293	5583	5858	6110	6329	6502	6612	6642	6567	6361	5990	5415	4589	3457	1953	0
2391	2584	2788	3000	3221	3448	3679	3913	4145	4372	4588	4785	4957	5092	5178	5201	5143	4981	4691	4240	3594	2707	1530	0
1873	2024	2183	2349	2522	2700	2882	3065	3247	3424	3593	3748	3882	3988	4055	4073	4028	3901	3674	3321	2814	2120	1198	0
1466	1585	1710	1840	1975	2114	2257	2400	2543	2681	2814	2935	3040	3123	3176	3190	3154	3055	2877	2601	2204	1660	938	0
1148	1241	1339	1441	1547	1656	1767	1880	1991	2100	2204	2298	2381	2446	2487	2498	2470	2393	2253	2037	1726	1300	735	0
899	972	1049	1128	1211	1297	1384	1472	1559	1645	1726	1800	1865	1915	1948	1957	1935	1874	1764	1595	1352	1018	575	0
704	761	821	884	949	1016	1084	1153	1221	1288	1351	1410	1460	1500	1526	1532	1515	1467	1382	1249	1059	798	451	0
552	596	643	692	743	795	849	903	956	1009	1058	1104	1144	1175	1195	1200	1187	1149	1082	978	829	625	353	0
432	467	504	542	582	623	665	707	749	790	829	865	896	920	936	940	929	900	847	766	649	489	276	0
338	366	394	424	456	488	521	554	587	619	649	677	701	720	733	736	728	705	664	600	508	383	216	0
265	286	309	332	357	382	408	434	459	484	508	530	549	564	574	576	570	552	520	470	398	300	170	0
207	224	242	260	279	299	319	340	360	379	398	415	430	442	449	451	446	432	407	368	312	235	133	0
163	176	189	204	219	234	250	266	282	297	312	325	337	346	352	354	350	339	319	288	244	184	104	0
	138	148	160	171	184	196	208	221	233	244	255	264	271	276	277	274	265	250	226	191	144	81	0
		116	125	134	144	153	163	173	182	191	199	207	212	216	217	214	208	196	177	150	113	64	0
			98	105	113	120	128	135	143	150	156	162	166	169	170	168	163	153	138	117	88	50	0
				82	88	94	100	106	112	117	122	127	130	132	133	131	127	120	108	92	69	39	0
					69	74	78	83	88	92	96	99	102	104	104	103	100	94	85	72	54	31	0
						58	61	65	69	72	75	78	80	81	82	81	78	74	66	56	42	24	0
							48	51	54	56	59	61	63	64	64	63	61	58	52	44	33	19	0
								40	42	44	46	48	49	50	50	49	48	45	41	35	26	15	0
									33	35	36	37	38	39	39	39	38	35	32	27	20	12	0
										27	28	29	30	31	31	30	29	28	25	21	16	9	0
											22	23	24	24	24	24	23	22	20	17	13	7	0
												18	18	19	19	19	18	17	15	13	10	6	0
													14	15	15	15	14	13	12	10	8	4	0
														11	12	11	11	10	9	8	6	3	0
															9	9	9	8	7	6	5	3	0
																7	7	6	6	5	4	2	0
																	5	5	5	4	3	2	0
																		4	4	3	2	1	0
																			3	2	2	1	0
																				2	1	1	0
																					1	1	0
																						0	0
																							0

Total investment costs of energy-saving measure:

t	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	18,0	19,0	20,0	21,0	22,0	23,0	24,0
I(t)	6945	6864	6782	6697	6611	6523	6434	6342	6248	6152	6054	5954	5852	5748	5641	5532	5420	5306	5190	5070	4948	4824	4696	4565	4432

Event tree for value of option on energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	2319	2791	3353	4021	4812	5749	6856	8163	9703	11421	13295	15335	17554	19967	22586	25427	28503	31829	35420	39289	43449	47912	52688	57785	63205
1		1758	2127	2569	3095	3722	4467	5351	6398	7636	9099	10718	12479	14391	16465	18713	21147	23776	26613	29669	32954	36476	40244	44264	48538
2			1313	1598	1941	2352	2844	3431	4130	4962	5949	7119	8504	10024	11671	13456	15386	17470	19717	22136	24734	27520	30499	33675	37051
3				964	1181	1444	1761	2143	2600	3148	3802	4581	5509	6611	7917	9338	10874	12531	14316	16236	18298	20506	22867	25382	28056
4					694	857	1056	1297	1588	1940	2364	2873	3482	4211	5080	6114	7340	8663	10086	11616	13257	15013	16890	18888	21011
5						489	609	756	935	1155	1421	1745	2135	2606	3172	3852	4664	5633	6773	7997	9309	10712	12209	13802	15493
6							335	421	528	660	821	1019	1262	1557	1915	2348	2871	3501	4258	5164	6217	7343	8543	9819	11173
7								223	284	359	453	569	713	891	1109	1376	1702	2099	2580	3161	3862	4705	5672	6700	7789
8									144	185	236	301	383	485	612	770	965	1204	1499	1859	2298	2832	3477	4257	5139
9										89	116	150	194	249	319	407	518	656	828	1042	1305	1630	2027	2513	3104
10											53	70	91	119	155	202	261	336	431	551	701	889	1122	1411	1768
11												30	40	53	70	93	122	160	209	272	352	454	583	746	950
12													16	21	29	39	52	70	93	123	163	215	281	367	476
13														8	11	15	20	27	37	51	69	92	123	164	218
14															3	5	7	10	13	19	26	35	48	66	90
15																1	2	3	4	6	8	12	17	23	32
16																	1	1	1	2	2	3	5	7	10
17																		0	0	0	1	1	1	2	3
18																			0	0	0	0	0	0	1
19																				0	0	0	0	0	0
20																					0	0	0	0	0
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4295	4155	4012	3865	3715	3561	3403	3242	3076	2906	2732	2554	2371	2183	1990	1792	1589	1380	1166	946	719	486	247	0

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
68950	75014	81383	88035	94940	102052	109309	116631	123914	131026	137801	144033	149469	153798	156643	157546	155956	151213	142526	128952	109369	82447	46611	0
53067	57846	62864	68107	73547	79150	84867	90637	96376	101983	107326	112246	116542	119973	122243	122993	121792	118123	111366	100784	85496	64463	36450	0
40628	44401	48362	52499	56792	61214	65725	70279	74810	79237	83460	87351	90756	93483	95302	95933	95036	92208	86963	78723	66800	50378	28492	0
30886	33871	37005	40276	43671	47167	50735	54336	57920	61424	64769	67855	70561	72738	74204	74741	74083	71913	67852	61447	52158	39348	22260	0
23257	25625	28110	30704	33395	36166	38995	41850	44693	47474	50131	52586	54745	56491	57681	58144	57673	56019	52885	47917	40692	30710	17379	0
17282	19167	21144	23208	25348	27551	29801	32072	34334	36549	38667	40629	42359	43767	44741	45147	44822	43572	41164	37321	31712	23945	13557	0
12603	14110	15689	17337	19046	20805	22600	24414	26221	27993	29690	31265	32660	33803	34607	34968	34757	33824	31985	29023	24679	18647	10564	0
8939	10149	11417	12739	14110	15521	16961	18417	19868	21292	22659	23931	25063	25999	26671	26996	26876	26190	24796	22524	19171	14498	8219	0
6069	7047	8071	9139	10245	11383	12545	13720	14893	16045	17153	18188	19114	19888	20456	20753	20703	20211	19166	17434	14858	11249	6384	0
3822	4618	5451	6319	7217	8142	9087	10042	10996	11935	12841	13690	14455	15102	15588	15864	15869	15529	14757	13449	11480	8704	4946	0
2207	2744	3399	4110	4847	5604	6378	7161	7944	8717	9463	10167	10806	11353	11776	12035	12083	11862	11304	10327	8835	6711	3820	0
1205	1522	1914	2397	2990	3617	4257	4905	5555	6196	6819	7409	7949	8418	8791	9037	9118	8990	8600	7883	6763	5150	2938	0
615	791	1012	1290	1636	2066	2596	3139	3683	4222	4748	5248	5711	6119	6453	6688	6796	6741	6482	5968	5140	3928	2247	0
288	379	495	644	834	1075	1377	1755	2217	2676	3126	3556	3958	4319	4622	4849	4978	4980	4823	4469	3870	2971	1707	0
121	163	219	292	387	511	671	876	1136	1466	1855	2231	2586	2909	3188	3409	3554	3601	3525	3295	2875	2221	1283	0
45	62	86	117	160	216	292	391	522	692	912	1194	1511	1805	2065	2281	2438	2521	2507	2375	2095	1634	951	0
14	20	29	40	57	79	110	152	209	286	389	525	705	940	1186	1398	1565	1675	1711	1655	1485	1174	692	0
4	5	8	12	17	24	35	49	70	100	140	196	273	377	518	706	881	1012	1087	1091	1007	814	488	0
1	1	2	3	4	6	9	13	19	28	41	59	85	123	176	249	352	493	598	649	633	532	329	0
0	0	0	0	1	1	2	2	4	6	9	13	20	30	45	67	100	147	216	303	339	311	204	0
0	0	0	0	0	0	0	0	0	1	1	2	3	5	8	12	19	29	45	71	110	138	106	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	4	7	11	18	30	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0	0	0	0	0	0	0
											0	0	0	0	0	0	0	0	0	0	0	0	0
												0	0	0	0	0	0	0	0	0	0	0	0
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															0	0	0	0	0	0	0	0	0
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																	0	0	0	0	0	0	0
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																						0	0
																							0

Binomial model of expansion option on solar water heater

Input parameters:			Intermediate parameters:		Solver:	
risk-free rate of return (r_f)	4,0%	*0,0392*	growth rate up movement (u=exp(σ*√Δt))	1,130	net present value (V-I)	-1205
discount rate (risk-adjusted) (ρ)	7,0%	*0,0677*	growth rate down movement (d=1/u)	0,885	5% of net present value	-60
exp. annual growth rate energy prices (α_{var})	7,0%	*0,0677*	risk-free rate per time interval (rdt=exp(r_f*Δt))	1,040	value of waiting (W)	2439
exp. annual st. deviation energy prices (σ_{var})	13,0%	*0,1222*	risk neutral prob. up movement (q=(rdt-d)/(u-d))	0,633	option value (F)	1234
time horizon energy systems (T)	48	years	risk neutral prob. down movement (1-q)	0,367	cel bepalen	-2499
investment costs energy-saving measure (I)	5700	Euros	length of time intervals (Δt=T/n)	1,000		
current annual variable energy costs savings	126	Euros	Output parameters:		Optimal investment timing:	
current additional annual fixed energy costs	0	Euros	net present value (V-I)	-1205	Z = α_{var} - 0,5*σ_{var}^2	0,06
additional annual maintenance costs	21	Euros	value of waiting (W)	2439	expected years	0,00
additional annual replacement costs	105	Euros	option value (F)	1234		

Event tree for energy price index:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79
1		0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71
2			0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52
3				0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02
4					0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07
5						0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53
6							0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33
7								0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39
8									0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66
9										0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08
10											0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63
11												0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28
12													0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00
13														0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78
14															0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61
15																0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48
16																	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38
17																		0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29
18																			0,11	0,13	0,14	0,16	0,18	0,20	0,23
19																				0,10	0,11	0,13	0,14	0,16	0,18
20																					0,09	0,10	0,11	0,13	0,14
21																						0,08	0,09	0,10	0,11
22																							0,07	0,08	0,09
23																								0,06	0,07
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25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78	150,04	169,55	191,59	216,50	244,64	276,44	312,38	352,99
16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78	150,04	169,55	191,59	216,50	244,64	276,44
13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78	150,04	169,55	191,59	216,50
10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78	150,04	169,55
7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99	117,51	132,78
6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44	92,02	103,99
4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78	72,07	81,44
3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95	56,44	63,78
3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12	44,20	49,95
2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63	34,62	39,12
1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99	27,11	30,63
1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79	21,23	23,99
1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71	16,63	18,79
0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52	13,02	14,71
0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02	10,20	11,52
0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07	7,99	9,02
0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53	6,25	7,07
0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33	4,90	5,53
0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39	3,84	4,33
0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66	3,00	3,39
0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08	2,35	2,66
0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63	1,84	2,08
0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28	1,44	1,63
0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00	1,13	1,28
0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78	0,88	1,00
0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61	0,69	0,78
	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48	0,54	0,61
		0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38	0,43	0,48
			0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29	0,33	0,38
				0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23	0,26	0,29
					0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18	0,20	0,23
						0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14	0,16	0,18
							0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,13	0,14
								0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09	0,10	0,11
									0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07	0,08	0,09
										0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,07
											0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04	0,05	0,05
												0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,04
													0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03
														0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03
															0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02
																0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02
																	0,01	0,01	0,01	0,01	0,01	0,01	0,01
																		0,01	0,01	0,01	0,01	0,01	0,01
																			0,00	0,01	0,01	0,01	0,01
																				0,00	0,00	0,01	0,01
																					0,00	0,00	0,00
																						0,00	0,00
																							0,00

Capitalisation factor:

t	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	18,0	19,0	20,0	21,0	22,0	23,0	24,0
K_{var}	48,0	47,0	46,0	45,0	44,0	43,0	42,0	41,0	40,0	39,0	38,0	37,0	36,0	35,0	34,0	33,0	32,0	31,0	30,0	29,0	28,0	27,0	26,0	25,0	24,0
K_{cpi}	18,7	18,6	18,5	18,4	18,2	18,1	18,0	17,9	17,7	17,6	17,4	17,2	17,1	16,9	16,7	16,5	16,3	16,1	15,8	15,6	15,3	15,1	14,8	14,5	14,2
K_0	14,1	14,0	14,0	14,0	13,9	13,9	13,8	13,7	13,7	13,6	13,5	13,5	13,4	13,3	13,2	13,1	13,0	12,9	12,7	12,6	12,5	12,3	12,1	12,0	11,8

Event tree for value of energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	6048	6692	7401	8181	9039	9982	11018	12154	13399	14762	16253	17883	19661	21600	23711	26005	28495	31194	34112	37261	40653	44298	48203	52374	56815
1		5241	5796	6407	7079	7818	8628	9518	10493	11561	12729	14005	15398	16916	18569	20366	22316	24429	26714	29181	31838	34692	37750	41016	44495
2			4539	5018	5544	6122	6757	7454	8218	9054	9968	10968	12059	13248	14542	15950	17477	19132	20921	22853	24934	27169	29564	32122	34846
3				3930	4342	4795	5292	5838	6436	7090	7807	8589	9444	10375	11389	12491	13687	14983	16384	17897	19527	21277	23153	25156	27289
4					3400	3755	4144	4572	5040	5553	6114	6727	7396	8125	8919	9782	10719	11734	12831	14016	15292	16663	18132	19701	21372
5						2941	3246	3580	3947	4349	4788	5268	5792	6363	6985	7661	8394	9189	10049	10977	11976	13050	14200	15429	16737
6							2542	2804	3091	3406	3750	4126	4536	4983	5470	6000	6574	7197	7870	8596	9379	10220	11121	12083	13108
7								2196	2421	2667	2937	3231	3552	3903	4284	4699	5148	5636	6163	6732	7345	8004	8709	9463	10265
8									1896	2089	2300	2530	2782	3056	3355	3680	4032	4414	4827	5272	5752	6268	6820	7411	8039
9										1636	1801	1982	2179	2394	2627	2882	3158	3457	3780	4129	4505	4909	5341	5804	6296
10											1410	1552	1706	1875	2058	2257	2473	2707	2960	3234	3528	3844	4183	4545	4931
11												1215	1336	1468	1611	1767	1937	2120	2318	2532	2763	3011	3276	3560	3861
12													1046	1150	1262	1384	1517	1660	1816	1983	2164	2358	2566	2788	3024
13														900	988	1084	1188	1300	1422	1553	1695	1846	2009	2183	2368
14															774	849	930	1018	1114	1216	1327	1446	1574	1710	1855
15																665	728	797	872	953	1039	1132	1232	1339	1452
16																	571	625	683	746	814	887	965	1049	1138
17																		489	535	584	637	695	756	821	891
18																			419	458	499	544	592	643	698
19																				358	391	426	464	504	546
20																					306	334	363	394	428
21																						261	284	309	335
22																							223	242	262
23																								189	206
24																									161
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25,0	26,0	27,0	28,0	29,0	30,0	31,0	32,0	33,0	34,0	35,0	36,0	37,0	38,0	39,0	40,0	41,0	42,0	43,0	44,0	45,0	46,0	47,0	48,0
23,0	22,0	21,0	20,0	19,0	18,0	17,0	16,0	15,0	14,0	13,0	12,0	11,0	10,0	9,0	8,0	7,0	6,0	5,0	4,0	3,0	2,0	1,0	0,0
13,9	13,5	13,2	12,8	12,4	12,0	11,6	11,1	10,6	10,1	9,6	9,1	8,5	7,9	7,3	6,6	5,9	5,2	4,4	3,6	2,8	1,9	1,0	0,0
11,6	11,3	11,1	10,9	10,6	10,3	10,0	9,7	9,3	9,0	8,6	8,1	7,7	7,2	6,7	6,1	5,5	4,9	4,2	3,5	2,7	1,9	1,0	0,0

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
61526	66502	71731	77196	82870	88715	94678	100693	106672	112503	118048	123133	127546	131024	133252	133844	132338	128179	120702	109114	92474	69664	39360	0
48184	52081	56176	60456	64900	69477	74147	78858	83540	88107	92449	96431	99887	102611	104356	104819	103640	100383	94527	85453	72421	54557	30825	0
37735	40787	43994	47346	50826	54410	58068	61757	65424	69000	72401	75520	78226	80360	81726	82089	81165	78614	74029	66922	56716	42726	24140	0
29552	31942	34454	37079	39804	42611	45476	48365	51237	54037	56701	59143	61263	62933	64003	64288	63564	61567	57975	52410	44417	33461	18905	0
23144	25015	26982	29038	31172	33371	35614	37877	40126	42319	44405	46318	47978	49286	50124	50347	49780	48216	45403	41044	34785	26205	14806	0
18125	19591	21131	22741	24413	26134	27891	29663	31424	33142	34776	36274	37573	38598	39254	39429	38985	37760	35557	32144	27242	20522	11595	0
14194	15342	16549	17810	19119	20467	21843	23231	24610	25955	27234	28408	29426	30228	30742	30879	30531	29572	27847	25173	21334	16072	9081	0
11116	12015	12960	13948	14973	16029	17106	18193	19273	20327	21329	22247	23045	23673	24075	24182	23910	23159	21808	19714	16708	12587	7111	0
8706	9410	10150	10923	11726	12553	13397	14248	15094	15919	16703	17423	18047	18539	18855	18938	18725	18137	17079	15439	13085	9857	5569	0
6818	7369	7949	8554	9183	9831	10492	11158	11821	12467	13081	13645	14134	14519	14766	14832	14665	14204	13375	12091	10247	7720	4362	0
5339	5771	6225	6699	7192	7699	8216	8738	9257	9763	10244	10686	11069	11371	11564	11615	11485	11124	10475	9469	8025	6046	3416	0
4182	4520	4875	5247	5632	6029	6435	6843	7250	7646	8023	8369	8668	8905	9056	9096	8994	8711	8203	7416	6285	4735	2675	0
3275	3540	3818	4109	4411	4722	5039	5359	5678	5988	6283	6554	6789	6974	7092	7124	7044	6822	6424	5808	4922	3708	2095	0
2565	2772	2990	3218	3454	3698	3946	4197	4446	4689	4921	5133	5317	5461	5554	5579	5516	5343	5031	4548	3855	2904	1641	0
2008	2171	2342	2520	2705	2896	3091	3287	3482	3673	3854	4020	4164	4277	4350	4369	4320	4184	3940	3562	3019	2274	1285	0
1573	1700	1834	1974	2119	2268	2420	2574	2727	2876	3018	3148	3261	3350	3407	3422	3383	3277	3086	2790	2364	1781	1006	0
1232	1331	1436	1546	1659	1776	1896	2016	2136	2252	2363	2465	2554	2623	2668	2680	2650	2566	2417	2185	1851	1395	788	0
965	1043	1125	1210	1299	1391	1485	1579	1673	1764	1851	1931	2000	2054	2089	2099	2075	2010	1893	1711	1450	1092	617	0
756	817	881	948	1018	1089	1163	1236	1310	1381	1450	1512	1566	1609	1636	1644	1625	1574	1482	1340	1136	855	483	0
592	640	690	742	797	853	910	968	1026	1082	1135	1184	1227	1260	1281	1287	1273	1233	1161	1049	889	670	379	0
463	501	540	581	624	668	713	758	803	847	889	927	961	987	1004	1008	997	965	909	822	696	525	296	0
363	392	423	455	489	523	558	594	629	664	696	726	752	773	786	789	781	756	712	644	545	411	232	0
284	307	331	357	383	410	437	465	493	520	545	569	589	605	615	618	611	592	558	504	427	322	182	0
223	241	259	279	300	321	342	364	386	407	427	445	461	474	482	484	479	464	437	395	335	252	142	0
174	188	203	219	235	251	268	285	302	319	334	349	361	371	377	379	375	363	342	309	262	197	112	0
137	148	159	171	184	197	210	223	237	250	262	273	283	291	296	297	294	284	268	242	205	155	87	0
	116	125	134	144	154	165	175	185	195	205	214	222	228	232	233	230	223	210	190	161	121	68	0
		98	105	113	121	129	137	145	153	161	168	174	178	181	182	180	174	164	148	126	95	54	0
			82	88	95	101	107	114	120	126	131	136	140	142	143	141	137	129	116	99	74	42	0
				69	74	79	84	89	94	99	103	106	109	111	112	110	107	101	91	77	58	33	0
					58	62	66	70	74	77	80	83	86	87	87	86	84	79	71	60	46	26	0
						48	52	55	58	60	63	65	67	68	69	68	66	62	56	47	36	20	0
							40	43	45	47	49	51	53	53	54	53	51	48	44	37	28	16	0
								33	35	37	39	40	41	42	42	42	40	38	34	29	22	12	0
									28	29	30	31	32	33	33	33	32	30	27	23	17	10	0
										23	24	25	25	26	26	25	25	23	21	18	13	8	0
											19	19	20	20	20	20	19	18	16	14	11	6	0
												15	15	16	16	16	15	14	13	11	8	5	0
													12	12	12	12	12	11	10	9	6	4	0
														10	10	10	9	9	8	7	5	3	0
															8	8	7	7	6	5	4	2	0
																6	6	5	5	4	3	2	0
																	4	4	4	3	2	1	0
																		3	3	3	2	1	0
																			2	2	1	1	0
																				2	1	1	0
																					1	1	0
																						0	0
																							0

Total investment costs of energy-saving measure:

t	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	18,0	19,0	20,0	21,0	22,0	23,0	24,0
I(t)	7253	7233	7211	7187	7162	7135	7106	7076	7043	7007	6970	6929	6886	6840	6790	6737	6681	6620	6555	6486	6412	6332	6247	6156	6059

Event tree for value of option on energy-saving measure:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	1234	1531	1895	2339	2877	3529	4315	5262	6397	7755	9284	10954	12775	14760	16921	19268	21815	24574	27557	30776	34242	37966	41955	46218	50756
1		855	1071	1338	1666	2068	2558	3155	3879	4754	5809	7076	8512	10076	11779	13629	15635	17809	20159	22695	25426	28360	31503	34860	38436
2			575	728	919	1155	1448	1809	2252	2794	3455	4259	5233	6408	7752	9212	10796	12512	14366	16367	18522	20837	23316	25966	28787
3				374	479	611	777	984	1242	1563	1959	2447	3046	3778	4671	5753	7006	8363	9829	11412	13115	14945	16905	19000	21231
4					235	304	392	504	646	825	1050	1331	1682	2116	2653	3314	4124	5114	6276	7530	8881	10331	11885	13545	15313
5						141	185	242	315	408	528	680	873	1116	1422	1803	2279	2868	3596	4491	5564	6717	7953	9273	10678
6							81	107	142	187	247	323	422	549	712	919	1181	1512	1927	2446	3091	3890	4874	5927	7049
7								44	59	79	106	141	188	249	329	433	567	740	961	1243	1600	2052	2619	3327	4206
8									22	30	41	56	76	103	139	186	249	331	439	580	762	997	1299	1684	2173
9										10	14	20	28	38	53	72	99	134	182	245	329	440	586	777	1025
10											4	6	9	13	18	25	35	48	67	92	127	174	237	321	434
11												2	3	4	5	7	11	15	22	30	43	60	84	117	162
12													1	1	1	2	3	4	6	9	12	18	26	36	52
13														0	0	0	1	1	1	2	3	4	6	9	14
14															0	0	0	0	0	0	1	1	1	2	3
15																0	0	0	0	0	0	0	0	0	0
16																	0	0	0	0	0	0	0	0	0
17																		0	0	0	0	0	0	0	0
18																			0	0	0	0	0	0	0
19																				0	0	0	0	0	0
20																					0	0	0	0	0
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5955	5843	5724	5596	5460	5314	5158	4990	4811	4620	4415	4196	3961	3710	3442	3154	2847	2518	2166	1789	1386	955	494	0

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
55571	60658	66007	71600	77410	83401	89521	95703	101861	107884	113633	118938	123584	127314	129810	130689	129491	125661	118536	107325	91088	68709	38867	0
42229	46237	50452	54860	59440	64163	68990	73867	78728	83487	88034	92236	95926	98901	100914	101665	100793	97865	92361	83663	71035	53602	30331	0
31780	34944	38270	41750	45366	49097	52911	56767	60613	64381	67986	71324	74265	76649	78284	78935	78318	76097	71863	65133	55330	41771	23647	0
23597	26099	28730	31482	34344	37298	40318	43375	46425	49418	52286	54947	57301	59223	60561	61133	60717	59049	55809	50620	43031	32506	18412	0
17189	19172	21258	23442	25713	28057	30457	32886	35314	37699	39990	42122	44016	45576	46682	47192	46933	45698	43237	39255	33399	25250	14312	0
12170	13747	15407	17145	18953	20821	22734	24673	26613	28522	30361	32078	33612	34888	35813	36274	36138	35242	33391	30354	25856	19567	11101	0
8240	9499	10825	12213	13659	15153	16685	18240	19799	21335	22819	24212	25464	26518	27300	27724	27684	27054	25681	23384	19948	15117	8587	0
5162	6172	7236	8351	9513	10715	11949	13203	14462	15707	16914	18052	19083	19963	20634	21028	21063	20641	19642	17925	15322	11632	6618	0
2791	3567	4426	5327	6266	7239	8239	9257	10282	11299	12288	13227	14086	14829	15413	15784	15878	15619	14913	13650	11698	8902	5076	0
1346	1759	2287	2958	3723	4517	5334	6168	7009	7847	8666	9449	10172	10809	11324	11677	11818	11686	11209	10302	8861	6765	3868	0
584	781	1041	1379	1818	2385	3059	3748	4446	5143	5829	6490	7107	7660	8122	8461	8638	8606	8309	7680	6639	5091	2922	0
223	307	420	571	772	1040	1392	1853	2438	3026	3608	4173	4707	5195	5614	5942	6147	6193	6037	5626	4899	3779	2181	0
74	104	146	205	286	396	546	750	1023	1387	1868	2358	2827	3264	3651	3969	4197	4304	4258	4018	3536	2753	1601	0
20	29	42	61	88	126	180	256	361	507	708	983	1355	1751	2113	2425	2669	2825	2865	2759	2468	1949	1147	0
4	7	10	15	22	32	47	70	102	149	216	312	448	640	908	1215	1473	1666	1774	1773	1632	1319	791	0
1	1	2	3	4	6	9	14	22	33	49	74	111	166	247	365	536	759	920	1000	978	826	513	0
0	0	0	0	0	1	1	2	3	5	8	12	19	29	45	70	109	168	258	395	465	440	294	0
0	0	0	0	0	0	0	0	0	0	1	1	2	3	4	7	11	19	31	51	83	137	123	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0	0	0	0	0	0	0
											0	0	0	0	0	0	0	0	0	0	0	0	0
												0	0	0	0	0	0	0	0	0	0	0	0
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M Total cost of ownership of initial energy concept

Table 15: investment costs of initial energy concept.

component	total costs
Construction and additional costs:[(a)]	
- reference energy concept	€10.260
- floor heating	€1.820
- variable sun screens	€680
Utility network connection costs:[(b)]	
- natural gas	€700
Total investment costs:	€13.460

Note: (a) The construction and additional costs are based on (AgentschapNL, 2010b).
(b) The utility connection costs are based on quotations of Bouwfonds.

Table 16: exploitation costs of initial energy concept.

component	annual costs t=0	growth rate	discount rate	discounted annual costs t=48	total costs
Variable energy costs:					
- variable costs natural gas	€432	7,0%	7,0%	€432	€20.736
- variable costs electricity	€856	5,0%	7,0%	€346	€26.772
Fixed energy costs:					
- fixed costs natural gas	€190	2,0%	7,0%	€19	€3.486
- fixed costs electricity	€250	2,0%	7,0%	€25	€4.587
Replacement costs:					
- heath generator	€65	0	7,0%	€3	€892
Maintenance costs:					
- heath generator	€150	0	7,0%	€6	€2.060
Total exploitation costs:					58.534

N Numerical results of sensitivity analysis

Table 17: effect of exogenous discount rate on net present value of measure (value of waiting).

	5,5%	7,0%	8,5%
PV-system	6671 (1698)	1292 (4103)	-2094 (5910)
heat pump	4514 (235) [(a)]	255 (2064)	-2417 (3768)
solar water heater	1243 (995)	-1205 (2439)	-2681 (3469)

Note: (a) The value of waiting is not significant and it is optimal to exercise the option.

Table 18: effect of growth rates of energy prices on net present value of measure (value of waiting).

	-1,5%	resp. 5% and 7%	+1,5%
PV-system	-2535 (6433)	1292 (4103)	7046 (1318) [(a)]
heat pump	-1725 (3347)	255 (2064)	3317 (532) [(a)]
solar water heater	-2868 (3687)	-1205 (2439)	1367 (843)

Note: (a) The value of waiting is not significant and it is optimal to exercise the option.

Table 19: effect of volatility rates of energy prices on net present value of measure (value of waiting).

	-1,5%	resp. 9% and 13%	+1,5%
PV-system	2808 (3216)	1292 (4103)	-9 (4931)
heat pump	1454 (1338)	255 (2064)	-772 (2763)
solar water heater	-525 (1890)	-1205 (2439)	-1780 (2921)

Table 20: effect of time horizon of energy systems on net present value of measure (value of waiting).

	T= 36 years	T = 48 years	T = 60 years
PV-system	-700 (3540)	1292 (4103)	3139 (4871)
heat pump	-1322 (2282)	255 (2064)	1992 (1987)
solar water heater	-2350 (2785)	-1205 (2439)	144 (2215)

O Questionnaire de Groene Kreek

bouwfonds
ontwikkeling

Aan de bewoners van dit adres,

Hoevelaken, 30 augustus 2011

In het kader van mijn studie aan de Technische Universiteit van Eindhoven doe ik voor Bouwfonds Ontwikkeling onderzoek naar energiezuinige huizen. De wijk de Groene Kreek is een voormalig project van Bouwfonds Ontwikkeling en heeft een duurzaam en energiezuinig karakter. Uw ervaringen wil ik gebruiken voor mijn aanbevelingen over de ontwikkeling van energiezuinige huizen die aansluiten bij de wensen van toekomstige kopers.

Graag wil ik u daarom vragen deze enquête in te vullen en te retourneren met bijgevoegde envelop. Het invullen van de enquête zal u ongeveer 15 minuten kosten.

Alvast mijn dank voor uw medewerking!

Namens Bouwfonds Ontwikkeling,

Koen van Cann

tel. 033-2539972

Aantal enquêtes verspreid: 65

Aantal enquêtes retour: 17

Percentage terug: 26%

1. In wat voor een type woning woont u?

0 vrijstaande woning 6%
0 semi-vrijstaande woning 25%
0 tussenwoning 50%
0 hoekwoning 19%

2. Bent u de eerste eigenaar van deze woning?

0 Ja 88%
0 Nee 13%

3. Hoe belangrijk vond u de energiezuinigheid van uw woning bij de aankoop van uw woning?

0 zeer belangrijk 44%
0 belangrijk 56%
0 niet belangrijk

4. Weet u ongeveer hoeveel u betaalt aan maandelijkse energiekosten (voor gas en elektriciteit)?

0 nee 6%
0 ja, 94% namelijk: 0 €0 - €100 38%
  0 €100 - €150 44%
  0 €150 - €200 13%
  0 €200 - €250 6%
  0 €250 - €300
  0 meer dan €300

5. Verwacht u dat de energieprijzen de komende jaren gaan stijgen, dalen of gelijk blijven?

0 sterk stijgen (meer dan 10%) 19%
0 licht stijgen (circa 5%) 81%
0 gelijk blijven
0 licht dalen (circa 5%)
0 sterk dalen (meer dan 10%)

6. Weet u hoe uw huidige woning wordt verwarmd?

0 nee 6%
0 ja, 94% namelijk: 0 HR-ketel of VR-ketel 56%
  0 warmtepomp 44%
  0 zonne-energie
  0 stadsverwarming of warmtenet
  0 gaskachel
  0 elektrische verwarming
  0 anders, namelijk …………………………………………………..

In het vervolg van deze enquête worden een aantal energiebesparende opties besproken die u in uw woning kan toepassen, of zijn toepast. Deze energiebesparende opties worden eerst kort toegelicht:

- De meeste woningen hebben een <u>hr-combiketel</u> in combinatie met radiatoren. Deze combiketel verbrandt aardgas om uw huis én tapwater te verwarmen.
- Een aantal woningen heeft een <u>warmtepomp</u> in combinatie met vloerverwarming. Een warmtepomp haalt warmte uit de bodem om uw huis én tapwater te verwarmen. Een warmtepomp is duurder in aanschaf dan een hr-combiketel maar goedkoper in gebruik. Tevens zorgt de vloerverwarming voor een gezonder en comfortabeler binnenklimaat.
- Een <u>zonneboiler</u> gebruikt zonnestraling om uw tapwater te verwarmen. Hiermee kunt u besparen op uw gasrekening.
- Met <u>zonnepanelen</u> op het dak van uw woning kunt u zelf groene stroom opwekken en besparen op uw elektriciteitsrekening.

7. Hoe goed bent u bekend met bovenstaande energiebesparende opties?

warmtepomp:	0 goed bekend 71%	0 enigszins bekend 29%	0 niet bekend
zonneboiler:	0 goed bekend 47%	0 enigszins bekend 53%	0 niet bekend
zonnepanelen:	0 goed bekend 71%	0 enigszins bekend 29%	0 niet bekend

8. Wist u dat uw woning toekomstvoorbereid is, zodat deze energiebesparende opties relatief eenvoudig toegepast kunnen worden?

0 ja 82%
0 nee 18%

9. Waren er al energiebesparende optie(s) toegepast toen u uw woning kocht?

0 nee 35%
0 ja, 65% namelijk: 0 zonneboiler (warm water) 25%
    0 warmtepomp 75%
    0 zonnepanelen (groene stroom)

Indien er destijds <u>geen</u> opties waren toegepast: ga verder naar vraag 10.
Indien er destijds <u>wel</u> opties waren toegepast: ga verder naar vraag 12.

10. Was het destijds een bewuste keuze om <u>geen</u> energiebesparende optie(s) toe te passen?

(indien ja dan a.u.b. maximaal twee redenen aankruisen)

0 nee 71%
0 ja, 29% omdat: 0 ik onbekend was met de techniek, kosten, besparingen etc.
    0 ik onzeker was over de restwaarde bij een eventuele verhuizing
    0 ik de extra investering niet kon betalen 33%
    0 ik de investering niet rendabel vond 33%
    0 ik energiebesparing niet belangrijk vond
    0 ik onzeker was over de terugverdientijd 33%
    0 ik wachtte op een verbetering van de techniek of hogere subsidies
    0 anders, namelijk

11. Hoe tevreden bent u nu over de energiezuinigheid van uw woning? > zie vraag 15

0 zeer tevreden
0 tevreden
0 neutraal
0 ontevreden, omdat ………………………………………………………………..
0 zeer ontevreden, omdat ………………………………………………………….

Ga verder naar vraag 16.

12. Was het destijds een bewuste keuze om wel energiebesparende optie(s) toe te passen?

(indien ja dan a.u.b. maximaal twee redenen aankruisen)

0 nee 10%
0 ja, 90% omdat:
    0 energiebesparing goed voor het milieu is 47%
    0 een energiezuinige woning meer waard is
    0 een energiezuinige woning sneller verkoopt
    0 de energierekening lager is 21%
    0 het binnenmilieu comfortabel en gezond is 11%
    0 de terugverdientijd acceptabel is 16%
    0 anders, namelijk 5% "Het is prettig om een huis te hebben dat aan de nieuwe eisen voldoet."

13. Wat was destijds ongeveer de meerprijs van de toegepaste energiebesparende optie(s)?

0 weet ik niet meer 65%
0 €0 - €6.000 6%
0 €6.000 - €8.000
0 €8.000 - €10.000
0 €10.000 - €12.000
0 €12.000 - €14.000 6%
0 €14.000 - €16.000
0 €16.000 - €18.000 6%
0 €18.000 - €20.000 12%
0 meer dan €20.000 6%

14. Wat waren destijds ongeveer uw verwachtingen ten aanzien van de jaarlijkse besparingen op energiekosten als gevolg de toegepaste energiebesparende optie(s)?

0 weet ik niet meer 59%
0 €0 - €100 6%
0 €100 - €200 12%
0 €200 - €300
0 €300 - €400
0 €400 - €500
0 €500 - €600
0 €600 - €700
0 €700 - €800 12%
0 meer dan €800 12%

15. Hoe tevreden bent u nu over de energiezuinigheid van uw woning? Vraag 11 én 15

0 zeer tevreden 35%
0 tevreden 41%
0 neutraal 18%
0 ontevreden, omdat 6% "Er maar 1 raam open kan in heel het huis"
0 zeer ontevreden, omdat ………………………………………………………….

16. In de afgelopen jaren zijn de prijzen voor gas en elektriciteit gestegen. Hierdoor zijn de mogelijke besparingen op de energiekosten gestegen terwijl de investeringskosten van de energiebesparende opties gelijk zijn gebleven. De energieprijzen en de mogelijke besparingen op de energiekosten zullen in de toekomst waarschijnlijk nog verder stijgen.

Bent u <u>momenteel</u> bereid om te investeren in energiebesparende optie(s) die nog niet zijn toegepast in uw huis? En welke van onderstaande energiebesparende optie(s) zou u dan overwegen? De verwachte terugverdientijd is gebaseerd op de historische stijging van energieprijzen en exclusief subsidies.

	investering	verwachte terugverdientijd	huidige besparingen
0 geen 82%	-	-	-
0 zonneboiler (warm water)	€ 3.000	12 jaar	€150 p.j.
0 warmtepomp	€ 12.000	14 jaar	€700 p.j.
0 zonnepanelen (groene stroom) 18%	€ 4.000	16 jaar	€170 p.j.

Indien u nu <u>geen</u> opties overweegt: ga verder naar vraag 17.
Indien u nu <u>wel</u> opties overweegt: ga verder naar vraag 18.

17. Wat zijn voor u de belangrijkste redenen om nu <u>niet</u> te investeren in energiebesparende optie(s)?

(a.u.b. maximaal twee redenen aankruisen)

0 ik ben onbekend met de techniek, kosten, besparingen etc.
0 ik ben onzeker over de restwaarde bij een eventuele verhuizing 6%
0 ik kan de investering niet betalen 22%
0 ik vind de investering niet rendabel 28%
0 ik vind energiebesparing niet belangrijk
0 ik ben onzeker over de terugverdientijd 17%
0 ik wacht op een verbetering van de techniek of hogere subsidies 17%
0 anders, namelijk 11% “Ik heb al maximaal geïnvesteerd” (2x)

Ga verder naar vraag 19.

18. Wat zijn voor u de belangrijkste redenen om nu <u>wel</u> te investeren in energiebesparende optie(s)?

(a.u.b. maximaal twee redenen aankruisen)

0 energiebesparing is goed voor het milieu 29%
0 een energiezuinige woning is meer waard
0 een energiezuinige woning verkoopt sneller
0 de energierekening is lager 43%
0 het binnenmilieu is comfortabel en gezond
0 de terugverdientijd is acceptabel 29%
0 anders, namelijk

19. Stelt u zich voor dat de prijzen voor gas en elektriciteit over een aantal jaren zijn <u>verdubbeld.</u> In dat geval zijn ook de mogelijke besparingen op de energiekosten verdubbeld terwijl de investeringskosten van de energiebesparende opties gelijk zijn gebleven.

Zou u <u>dan</u> bereid zijn om te investeren in energiebesparende optie(s) die nog niet zijn toegepast in uw huis? En welke van onderstaande energiebesparende optie(s) zou u dan overwegen? De verwachte terugverdientijd is gebaseerd op de historische stijging van energieprijzen en exclusief subsidies.

	investering	verwachte terugverdientijd	huidige besparingen
0 geen 47%	-	-	-
0 zonneboiler (warm water) 12%	€ 3.000	6 jaar	€300 p.j.
0 warmtepomp	€ 12.000	7 jaar	€1350 p.j.
0 zonnepanelen (groene stroom) 47%	€ 4.000	8 jaar	€350 p.j.

Indien u dan <u>geen</u> opties overweegt: ga verder naar vraag 20.
Indien u dan <u>wel</u> opties overweegt: ga verder naar vraag 21.

20. Wat zijn voor u de belangrijkste redenen om bij een verdubbeling van de energieprijzen <u>niet</u> te investeren in energiebesparende optie(s)?

(a.u.b. maximaal twee redenen aankruisen)

0 ik ben onbekend met de techniek, kosten, besparingen etc.
0 ik ben onzeker over de restwaarde bij een eventuele verhuizing
0 ik kan de investering niet betalen 22%
0 ik vind de investering niet rendabel 22%
0 ik vind energiebesparing niet belangrijk
0 ik ben onzeker over de terugverdientijd 33%
0 ik wacht op een verbetering van de techniek of hogere subsidies
0 anders, namelijk 22% “Ik heb al maximaal geïnvesteerd” (2x)

Ga verder naar vraag 22.

21. Wat zijn voor u de belangrijkste redenen om bij een verdubbeling van de energieprijzen <u>wel</u> te investeren in energiebesparende optie(s)?

(a.u.b. maximaal twee redenen aankruisen)

0 energiebesparing is goed voor het milieu 29%
0 een energiezuinige woning is meer waard
0 een energiezuinige woning verkoopt sneller 10%
0 de energierekening is lager 38%
0 het binnenmilieu is comfortabel en gezond
0 de terugverdientijd is acceptabel 24%
0 anders, namelijk

22. Met PV-panelen kunt u zelf groene stroom opwekken. Stel dat de verwachte terugverdientijd van PV-panelen inclusief subsidie 8 jaar is. De uiteindelijk gerealiseerde terugverdientijd is afhankelijk van de toekomstige ontwikkeling van de elektriciteitsprijs. Bent u hierdoor eerder of later bereid te investeren in PV-panelen?

0 eerder investeren 38%
0 geen invloed 63%
0 later investeren

23. Wat is u leeftijd? ……… jaar gemiddeld 52,9

24. Wat is uw geslacht?

0 man 76%
0 vrouw 24%

25. Uit hoeveel personen bestaat uw huishouden, inclusief uzelf? ……… personen gemiddeld 2,6

26. Kunt u een indicatie geven van het gezamenlijke maandelijkse netto inkomen van uw huishouden? (niet verplicht)

0 nee 41%
0 ja, 59% namelijk:
  0 €0 - €1.000
  0 €1.000 - €2.000 20%
  0 €2.000 - €3.000 10%
  0 €3.000 - €4.000 20%
  0 €4.000 - €5.000 20%
  0 €5.000 - €6.000 30%
  0 €6.000 - €7.000
  0 meer dan €7.000

27. Bent u bereid om in de toekomst deel te nemen aan een consumentenpanel over de energiezuinigheid van huizen?

0 nee
0 ja, ik vul hieronder mijn contactgegevens in.

28. Bent u geïnteresseerd in de resultaten van dit onderzoek?

0 nee
0 ja, ik vul hieronder mijn contactgegevens in.

29. Hebt u nog opmerkingen over de enquête of over de energiezuinigheid van uw huis?

0 nee
0 ja, namelijk: …………………………………………………………………………….
…………………………………………………………………………….
…………………………………………………………………………….
…………………………………………………………………………….

30. Mijn contactgegevens zijn (niet verplicht):

naam: ……………………………………………………
adres: ……………………………………………………
postcode: …………………………………………………

- einde enquête –