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Evaluation of energy performance indicators and financial aspects of energy saving techniques in residential real estate

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ABSTRACT

The energy consumption in the existing residential building stock accounts for about 40% of the total energy consumption in the built environment. Different types of energy performance indicators to assess the energy consumption of buildings were and still are internationally under development. In this paper we compare the methodologies and accuracies of three Dutch energy performance indicators by applying them to eight houses. This application shows that the actual domestic energy use is linearly correlated with the estimated energy consumption given by the energy performance indicators, but 7–25% lower.

Based on the energy performance indicators and actual energy use, we offer a methodology to incorporate additional revenues within the financial analysis of energy saving techniques. These revenues are related to the value of the dwelling in which the techniques are installed. We use the same houses to analyse the financial returns on energy saving investments. By assigning the value increase of real estate to two popular specific energy saving techniques, namely wall and roof insulation, it is found that the payback period could be 40–50% shorter than when it is solely based on investment costs and energy prices.

1. Introduction

Buildings account for a large part of the annual energy consumption in modern societies. Within the European Union (EU) the energy use by the built environment is more than 40% of the total energy consumption [1]. In order to quantify the effect of energy saving measures in the built environment different methodologies with accompanying indicators were and still are being developed. Because of the European Energy Performance of Buildings Directive (EPBD) [2], many indicators have been developed to express the energy performance of European buildings by an energy label with a classification of A to G. Research [3,4] shows that real estate objects with a green energy label have a higher value than objects with a red energy label that addresses a relatively high energy use. Research among Swiss residents also shows that they expressed a certain willingness to pay for energy saving measures exists [5]. It is not known how much residents of other countries would wish to invest, but by making the benefits more explicit the application of energy saving measures will probably only increase. However, a methodology has not yet been offered to assign this value increase to specific adopted energy saving techniques in order to reduce the payback period of these individual techniques.

Now that Energy Performance Certification is compulsory within the European Union, it might be useful to relate the value of real estate objects with the life cycle costs of energy saving measures. In this paper we focus on the energy consumption of existing dwellings and the financial yield of energy saving measures. The aim is to get a better understanding of the accuracy of the indicators in relation to the physical state of the building stock. Next we would like to specify in which way energy saving techniques can generate financial benefits, because little information is available about the financial efficiency of energy saving techniques within regular dwellings. In our approach we will apply energy performance indicators, actual historical user data and indirect benefits of the increasing value of real estate.

The first part of this study presents three methodologies to express the energy performance of houses. In November 2007 there were approximately seven million houses in the Netherlands [6]. The average total energy consumption of these houses decreased by 16.6% over the last decade, but the electric energy use increased by 1.1% (see Fig. 1) [7]. At present the total average energy use per household is 70 GJ/year, of which 12 GJ/year is electric energy use. It is assumed that the energy use can be

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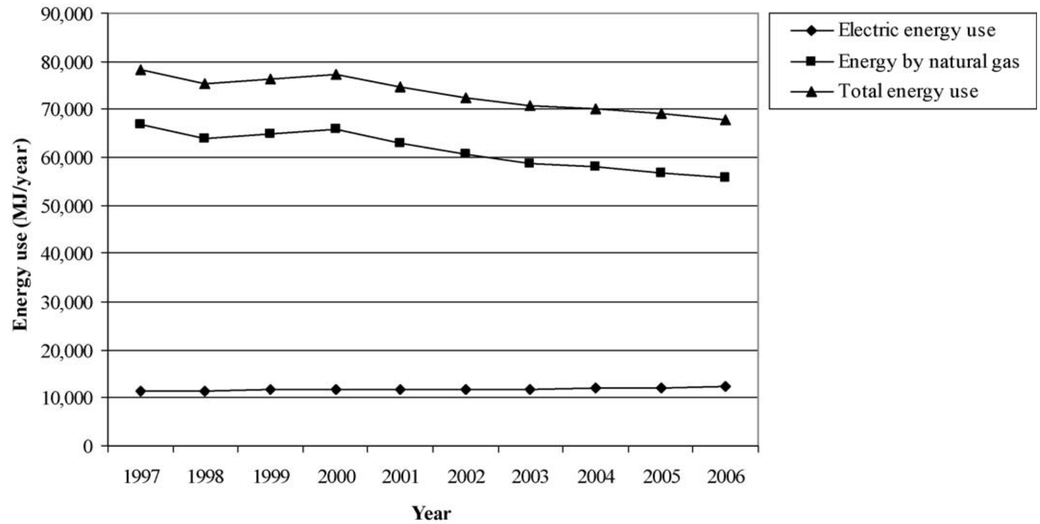


Fig. 1. Average electric energy use and natural gas consumption per household in the Netherlands during the last 10 years [6].

reduced significantly in the forthcoming decade under influence of European and Dutch policies. In order to be able to compare different new houses with regards to their energy performance, the Energy Performance Coefficient is in use since 1995. For existing dwellings another indicator, the Energy Index, is applied since 2000. In 2008 a new Energy Index was introduced, in line with the EPBD, for existing and new residential real estate. Each of these indicators will be explained in Section 2.

In Section 3 a case study on eight Dutch houses provides insights into how these three indicators reflect the energy consumption and how they are related to the actual energy consumption.

The second part of this study, in Sections 4 and 5, concerns the eventual financial benefits of investments in energy saving techniques. The amount of energy that can be saved, can be forecast by using the energy performance indicators. In Section 4 a new formula is introduced to incorporate the value increase of residential real estate in the Net Present Value of an adopted energy saving technique. To assess the effectiveness of the new formula, two different energy saving techniques in two houses will be evaluated in terms of energy consumption and finance in Section 5. We will complete our paper with a discussion and conclusions

2. Energy performance indicators for residential real estate

In The Netherlands three indicators are in use to express the energy performance of buildings:

(1) EPC: for new buildings regulated in 1995;
(2) EI_{old}: for existing buildings voluntary proposed in 2000;
(3) EI_{new}: for existing buildings regulated in 2008.[1]

In this section we will describe these indicators and the variables used to determine them. In the Netherlands 10% of the houses are relatively new and meet the Energy Performance Coefficient (EPC). This first indicator was formally incorporated in the Building Code implemented in 1995. The older existing building stock, consisting of more than six million dwellings, does not need to comply with this EPC. Dwellings built before 1945 use on average 31% more natural gas (the common fuel for space heating in The Netherlands) than dwellings from the period 2000 to 2004 [6]. The former Energy Index (EI_{old}), taken from the Energy Performance Advice (EPA), was developed to calculate the energy performance of these older dwellings and will be the second methodology to be presented. In January 2008 the Dutch government adopted a new indicator for existing dwellings. This Energy Index (EI_{new}) is the third indicator to be considered in this paper. It is a direct result of the Dutch implementation of the European EPBD.

All three indicators are based on equations that relate forecasted and permissible energy use. The forecasted energy use is based on the efficiency of the installed equipment, heat demand, warm tap water use, lighting, etc. The permissible energy use is mainly based on the size of the object. These indicators enable one to estimate the potential energy savings of a broad range of techniques. The indicators will now be presented in more detail.

2.1. Energy Performance Coefficient

The EPC for new buildings was developed by the Netherlands Normalisation Institute (NNI). Two standards are in use. NEN 5128 addresses the energy performance of dwellings and NEN 2916 speaks of the energy performance of offices. The latter has been discussed by Pati et al. [8]. For dwellings the EPC is calculated as follows [9]:

$$EPC = \frac{Q_{total:EPC}}{C_1 \times A_{gs;EPC} + C_2 \times A_{ts;EPC}} \times \frac{1}{C_{EPC}} \quad (1)$$

In which:

EPC: Energy Performance Coefficient
$Q_{total:EPC}$: characteristic yearly energy use of the new house based on NEN 5128 [9] (MJ)
$A_{gs;EPC}$: total ground surface (m^2)
$A_{ts;EPC}$: total thermal transmission surface (m^2)
C_1, C_2: numerical correction factor[2] (330 MJ/m^2, 65 MJ/m^2)
C_{EPC}: correction factor to fit past EPC results.

The characteristic yearly energy use (expressed by $Q_{total:EPC}$) totals 10 categories of energy consumption [9]:

[1] There is no penalty for non-adoption.

[2] These values are chosen in such a way that a standard house with EPC = 1.0 roughly equals a natural gas consumption of 1000 m^3.

1. *Energy for heating*: energy needed to heat the house to a temperature of 18 °C for a period of 1 year by the installed heating system. Besides the physical characteristics of the building, the efficiency of the heat generation, distribution, and delivery systems are taken into account;
2. *Additional energy*: auxiliary electric energy needed to operate the heating system;
3. *Heating water*: energy to heat tap water for doing the dishes, showering, bathing, etc.;
4. *Energy for fans*: electric energy needed for mechanic ventilation;
5. *Energy for lighting*: electric energy use for lighting based on 6.0 kWh/m^2 year for the total floor surface at the efficiency rate of a standard power station of 39%;
6. *Summer comfort*: fictive energy use to lower the inside temperature to 24 °C, if this temperature is exceeded during summer. This category is included to make sure that overheating of a house is prevented, for example, by installing shades;
7. *Energy used for cooling*: this category only applies when cooling techniques have been adopted;
8. *Energy used for moisturising*: this category reflects on a rare situation;
9. *Energy generation by photovoltaic systems*: the adoption process of photovoltaic systems on top of Dutch dwellings shows a small acceleration because of recent subsidies;
10. *Energy generation by combined heat and power systems*: microcogeneration systems for individual dwellings can be classified as innovative techniques in an experimental stage.

2.2. Old Energy Index

In the EPA-methodology, introduced in January 2000, the EI_{old} is calculated by [10]:

$$EI_{old} = \frac{Q_{total:EI\,old} \times A_{ts;EI\,old} \times C_3}{C_4 \times A^2_{ts;EI\,old} + C_5 \times Q_{total:EI\,old} \times A_{gs;EI\,old}} \tag{2}$$

In which:

EI_{old}: Energy Index calculated within the EPA procedure
$Q_{total;EI\,old}$: characteristic yearly energy use of the existing house based on EPA 4.02 [11] (MJ)
$A_{gs;EI\,old}$: total ground surface (m^2)
$A_{ts;EI\,old}$: total thermal transmission surface (m^2)
C_3, C_4, C_5: numerical correction factors 0.13, 56 (MJ/m^2), 0.06.

To express the energy performance of an existing house and to recommend energy saving measures for dwellings, the EPA was developed by SenterNovem (Dutch national agency for innovation and sustainable development). The output of the EPA is given in m^3 natural gas for generating heat and kWh for the electric energy use. By using an average caloric value of natural gas of 33.41 MJ/m^3 and a conversion rate of 3.6 MJ/kWh, it is possible to express the results in MJ. In this methodology the total foreseen energy use ($Q_{total;EI\,old}$) for existing houses is the equivalent of the characteristic energy use of the Energy Performance Coefficient ($Q_{total:EPC}$) for new houses. However, only four categories of energy use are covered by $Q_{total;EI\,old}$ [11]:

1. *Energy for heating*: energy needed to heat the dwelling. The standard value of 18 °C can be altered depending on the real indoor temperature or the general presence of the habitants;
2. *Additional energy*: auxiliary electric energy needed to operate the heating system;
3. *Heating water*: within the calculation procedure of this EPA it is not, unlike the calculation procedure of the EPC, necessary to specify the lengths of hot water pipes. One does need to specify if pipe insulation, water saving shower heads, bath, dishwasher, and reduced pipe lengths are applied or not;
4. *Energy for lighting*: the efficiency of the power station is not incorporated. The standard energy consumption of 6 kWh/m^2 year leads therefore to approximately 39% higher values for the energy consumption of lighting in the EPC than in the EI_{old}.

2.3. New Energy Index

The combined method for existing and new buildings uses the following equation to calculate a new type of Energy Index (EI_{new}) [12]:

$$EI_{new} = \frac{Q_{total;EI\,new}}{C_6 \times A_{gs;EI\,new} + C_7 \times A_{ts;EI\,new} + C_8} \tag{3}$$

In which:

EI_{new}: Energy Index calculated to comply with the EPBD
$Q_{total;EI\,new}$: characteristic yearly energy use of a house based on ISSO 82 [12] (MJ)
$A_{gs;EI\,new}$: total ground surface (m^2)
$A_{ts;EI\,new}$: total thermal transmission surface (m^2)
C_6, C_7, C_8: numerical correction factors 155 (MJ/m^2), 106 (MJ/m^2) and 9560 (MJ).

With the implementation of the EPBD proclaimed by the European Union (EU) Parliament and Council, new regulations are being developed by the central governments of the EU member states. In the Netherlands it was necessary to develop one method to calculate the energy performance of buildings. The energy need of a dwelling, $Q_{total;EI\,new}$, in Eq. (3) covers the same categories of energy consumption and underlying assumptions as $Q_{total:EPC}$ of Eq. (1), therefore their values are almost similar. The EI_{new} of the analysed building will be used in an energy certificate with an alphabetical classification. The classification or label A expresses the best energy performance ($EI_{new} < 1.05$) and a label G the worst ($EI_{new} > 2.90$).

3. Comparison of energy performance indicators and actual energy consumption

This section presents a case study involving eight existing houses. For each house the three presented energy performance indicators were calculated with the purpose of:

1. Comparing the values of three different energy performance indicators.
2. Comparing these theoretical values with empirical data on energy use.
3. Assessing the accuracy of the indicators.
4. Assessing the impact on the energy use of modifications to the houses.

3.1. Descriptions of the houses involved in the case study

Dutch houses are in general designed and constructed for relatively long service life times of 50–100 years. The housing stock increases by approximately 1% per year. This increase consists of highly insulated and energy efficient houses, therefore the existing building stock offers the biggest challenge in saving energy. Furthermore, it was an important consideration that the houses in the case study should be able to represent the existing building stock which comprises approximately 100 years of residential real estate development. The development of cavity walls, double glazing, insulation, and efficient natural gas boilers are some of the most important implemented breakthroughs within the set of houses. Formal regulations on energy efficiency in the built environment were introduced in 1992 for newly built houses.

The scope of this research is limited to adopting energy saving measures in houses built before the first regulation involving the EPC. Considering the scope of this research, the youngest house in the case study was built in 1992. Cavity walls were introduced in the third decade of the last century and therefore the oldest house in the collection dates from the year 1913. The eight low to middle priced houses were built according to the specification in Table 1. The average value of the eight dwellings of approximately € 267,000 – is slightly higher than the national average of € 226,000. Table 1 shows, besides some basic specifications, the results of the calculations on thermal resistances of floor, walls and roof. These calculations were made using the information on the original drawings of the house and by visual inspection by the first author. We used this data to calculate the EPC, EI_{old}, and EI_{new}.

The physical quality of a house and the applied installations are of great importance for its energy consumption. In the end it is not these technical conditions, but the behaviour of the users that can make a large difference. Hence, the owners of the houses were asked to supply data on their electric energy use and natural gas consumption for the past years. Some of the owners (house 3 and 5) could supply this data for more than 15 years.

Figs. 2 and 3 give insights in the effect of technical measures, as well as the effect of user behaviour. For house 4 and house 6 a significant decrease in electric energy consumption occurred in resp. 2004 and 2006, due to an adolescent leaving the parental house. House 1 has been subjected to steady increasing electric energy consumption, because of three additions to the family. The increasing electric energy consumption of house 5 – starting in 2004 – was caused by the instalment of electric floor heating in the bathroom. A few changes in energy consumption could not be explained by specific social or technical means, for instance in case of house 3 in 1990 and 1994. Besides these few alterations, a relatively steady electric energy consumption seems to exist per house. The natural gas consumption in Fig. 3 shows even smaller changes during time than the electric energy use does.

3.2. Theoretical energetic analyses

The collected specifications of the cases (shown in Table 1) are used to compute the EPC, EI_{old} and the EI_{new} with three computer programmes, named National Practical Directive (Nationale Praktijk Richtlijn—NPR) 5129 [13], Energy Performance Advice (Energie Prestatie Advies—EPA) [11] and Energy Performance Certificate Software for Residential Real Estate (Energieprestatie Certificaatsoftware Woningbouw—ECW) [14]. The computer program NPR 5129 version 2.02 of 2005 was used to calculate the EPC. The EI_{old} was calculated with the basic software edition EPA version 4.02 of June 2003 and ECW version 1.11 of October 2007 was used to calculate EI_{new}.

The EPC values range from 1.15 for the youngest house (number 8) to 2.66 for the oldest house (number 1; see Fig. 4). The values of the EPC are higher for older houses with exception of house 2 and 3, which both have undergone refurbishments. For instance house 2 with an EPC 1.78 has been provided with thermal insulation, very high performance glazing and a highly efficient furnace. House 3 has an EPC of 1.83, without the recently installed roof insulation the EPC would not be lower than 2.07.

The values of the EI_{old} do not show the same sequence in energy performance as the values of the EPC. Especially the additional energy use and the energy needed for heating water influence the performance of the last two houses, which are connected to a district heating system. The values of EI_{old} range from 0.62 for house 8 to 1.11 for house 1. Although there is a significant difference between the EPC's of house 5, 6, and 7, their specific EI_{old}'s of 0.86, 0.84, and 0.85, respectively, are almost the same. The energy to heat water for house number 7 is estimated by EPA to be much higher than for house number 5 and 6, because of the different appreciations of the EPA-methodology and EPC-methodology on the efficiency of district heating regarding to water heating (see Table 2).

Values for EI_{new} range from 2.77 (label F) up to 1.02 (label A). Again the oldest house (house 1) features the worst theoretical performance and the youngest building (house 8) the best. The sequence in energy performance is almost the same to the EPC; only houses 2 and 3 changed positions, because the estimated energy use on heating water was increased for house 2.

3.3. Energy analyses based on user data

Recent figures on the actual energy use by the inhabitants of the houses have been used to recalculate the energy performance indicators by using the annual $Q_{total;actual}$ to replace $Q_{total;EPC}$, $Q_{total;EI\ old}$, and $Q_{total;EI\ new}$ (see Fig. 5).

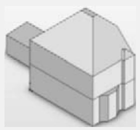
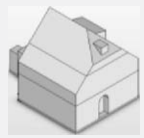
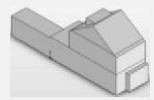
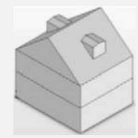
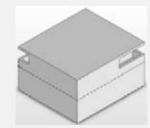
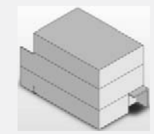
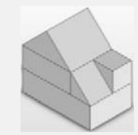
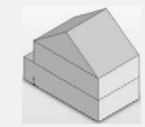
On average the performance ratios show that theoretical and actual values based on the EI_{old} and the EI_{new} do not differ as much as the values based on the EPC. Reflecting on these performance ratios, only houses 2 and 3 seem to have a performance that complies with the theoretical results. In theory, house 1 should relatively have been the largest energy consumer, but in practice it obtains a second place regarding its total annual energy consumption. The energy consumption per person shows even a better performance, but the energy performance indicators do not take the number of inhabitants into account. Regarding the values on EI_{old} it seems that three clusters of houses can be made, namely a first cluster consisting of houses 5 and 7, a second cluster with houses 2 and 4 and a third cluster with houses 1 and 3. When the theoretic and actual energy use (Q_{total}) are compared to each other, the actual energy use is 14.5% lower ($\sigma = 0.19$) than the energy use according to the software. The EI_{old} based on Eq. (2) and EI_{new} based on Eq. (3) seem to give results for Q_{total} that are closer to the real life situation than the EPC base on Eq. (1). However, the standard deviation for the $Q_{total;actual}/Q_{total;EPC}$ ratios is smaller than for $Q_{total;actual}/Q_{total;EI\ old}$ and $Q_{total;actual}/Q_{total;EI\ new}$.

By combining the theoretic and user data based indicators for all houses in one figure (see Fig. 6), it becomes clear that the performance quotient on EI_{old} shows a smaller dispersion than the results of EPC and EI_{new}. Although the methodology underlying EI_{old} gives quite realistic prognosis (93,3% with σ 0.191) on the annual energy consumption, the computed results for the indicator itself do not cover a broad range to reflect on this forecasted or actual annual energy consumption. For example, house 2 consumes in reality four times more energy than house 7 (see Table 2), but based on the transmission surfaces the values for EI_{old} only differ a factor 1.38 (see Fig. 5).

Furthermore, it can be seen that houses 2 and 3 are not close to the linear trend lines of the EPC and EI_{new}. When houses 2 and 3 are excluded from the data set, the relation $Q_{total;actual}/Q_{total;theory}$ shows a value of 77.2% with a standard deviation of only 0.12. The standard deviation is only 0.076, when the actual energy use is related to $Q_{total;EPC}$. The actual energy use is in that case on average 67.2% of the theoretical $Q_{total;EPC}$.

In the next section we will first present a new way to express the financial value of energy saving techniques, before assessing the impact on the energy use of extending a house and of installing roof installation.

Table 1
Basic characteristics of the eight houses.

	House 1	House 2	House 3	House 4	House 5	House 6	House 7	House 8
Year of construction	1913	1925	1939	1948	1964	1972	1982	1992
Building type	Semi-detached house	Detached house	Row house	Semi-detached house	Row house	Row house	Row house	Semi-detached house
Shape of the object								
Market value	€ 270,000	€ 365,000	€ 125,000	€ 280,000	€ 350,000	€ 324,000	€ 160,000	€ 265,000
Habitants	5	5	3	2	2	2	2	2
Total surface floors (m^2)	125.00	170.95	102.74	145.04	148.74	174.98	100.45	124.17
Surface building shell (m^2)	354.5	440.2	196.9	262.1	296.2	214.1	158.3	232.5
Perimeter (m)	25.43	50.40	16.10	21.48	23.56	14.00	10.80	19.96
Thermal resistance walls (m^2K/W)	0.21	0.28–1.77	0.41–1.19	0.41	0.41	0.50	1.73	2.84
Thermal resistance floor (m^2K/W)	0.22	0.07	0.09	1.65	0.42	0.03	0.68	2.39
Thermal resistance roof (m^2K/W)	2.13	1.38	1.19–2.5	1.76	2.84	2.22	1.41	2.57
Type(s) of glazing (W/m^2K)	Mainly single 5.2	Very high performance 1.8–2.1	Mainly high performance 2.3	Mainly single with double window frame 2.8–4.5	Mainly double with aluminium frames 3.0–5.2	Mainly double and high performance 2.8-5.2	Double glazing with wooden frames 2.9	Very high performance 1.8
Infiltration[a] ($dm^3/s\,m^2$)	1.4	1.4	1.4	1.4	1.2	1.2	1.2	1.0
Heating system	Highly efficient natural gas furnace	Highly efficient natural gas furnace	Traditional natural gas furnace	Efficient natural gas furnace	Efficient natural gas furnace	Efficient natural gas furnace	District heating	District heating
Length of pipes for heated water (m)	Bathroom 3, kitchen 3.5	Bathroom 3, kitchen 1, electric boiler	Bathroom 4.5, kitchen 7.5	Bathroom 2, kitchen 5.5	Bathroom 10, kitchen 7.5	Bathrooms 9, kitchen 7.5	Bathroom 15, kitchen 7.5	Bathroom 11, kitchen 7

[a] The specific rates of infiltration are based on a standardized infiltration of 1.0–1.43 $dm^3/s\,m^2$ and the fact that flat roof houses have a lower infiltration rate than gable roof houses.

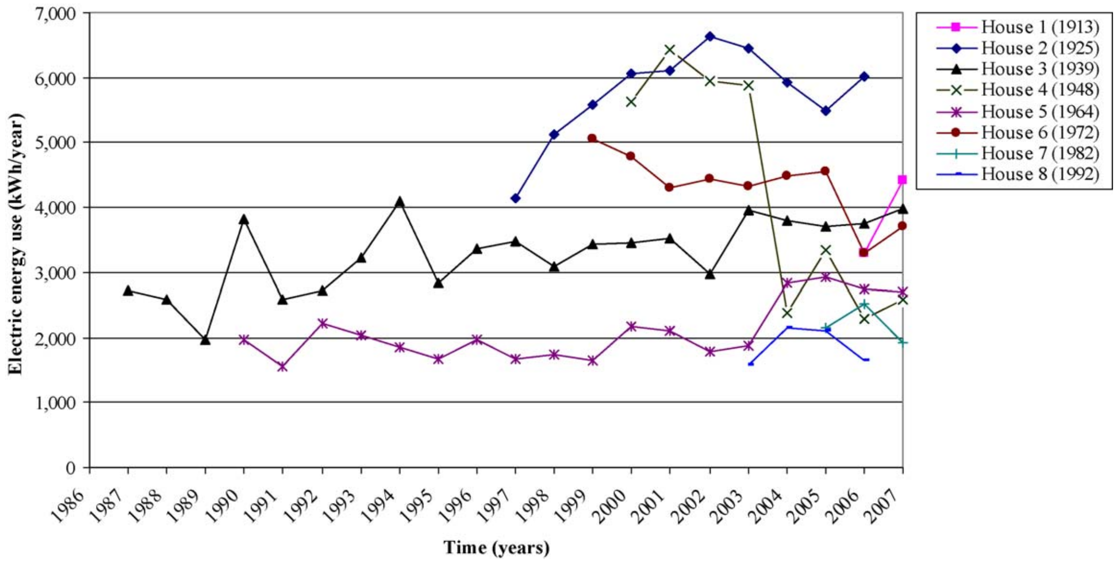


Fig. 2. Annual electric energy use per case study object based on object related energy bills.

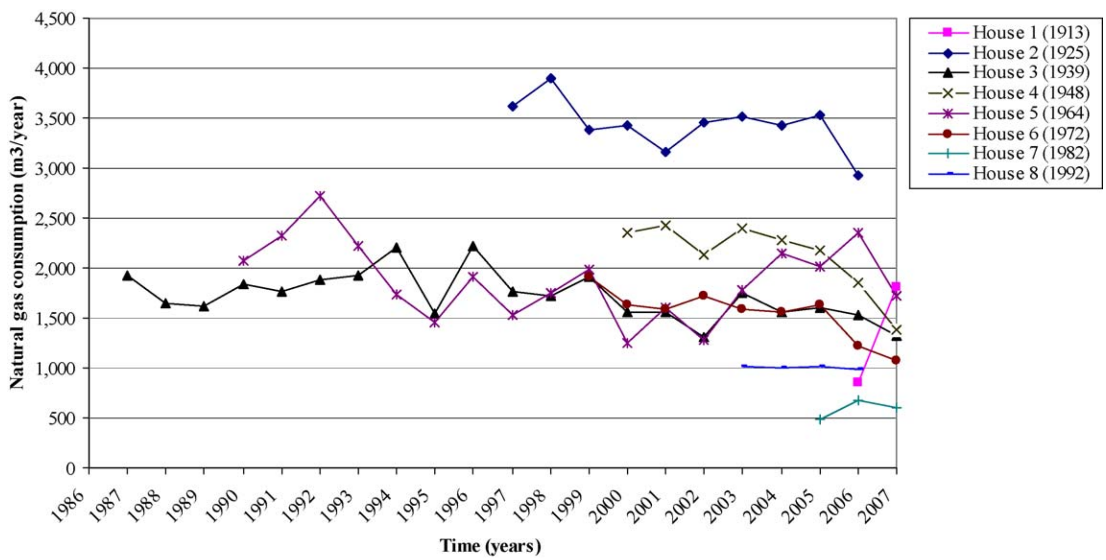


Fig. 3. Annual natural gas consumption per case study object based on object related energy bills.

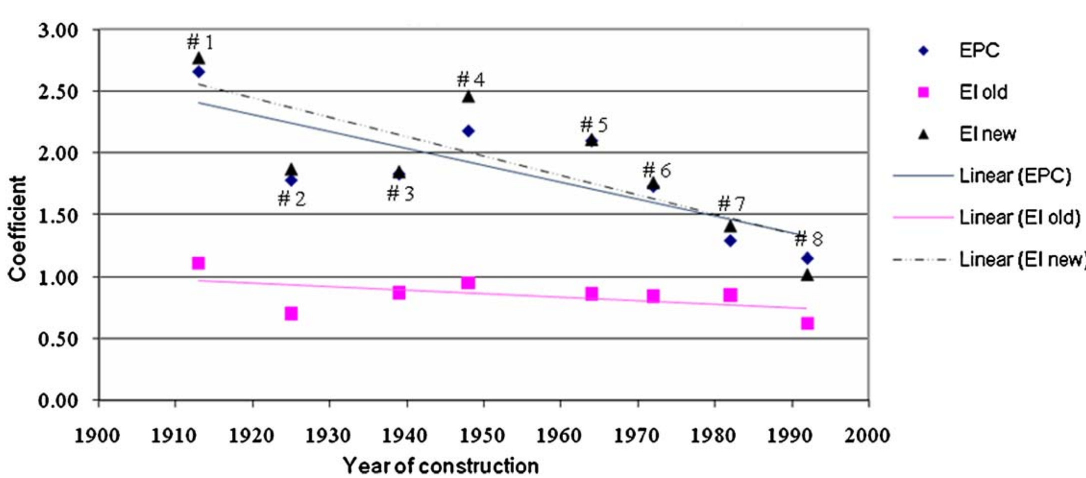


Fig. 4. Results per case study object on the energy performance expressed by the three standard energy performance indicators.

Table 2
Specifications and indicators for the energy performance of the eight houses.

	House 1	House 2	House 3	House 4	House 5	House 6	House 7	House 8
Theoretical results EPC								
Energy for heating (MJ)	144,314	125,334	57,496	118,491	105,514	67,941	38,370	40,485
Additional energy (MJ)	2,935	4,006	4,909	3,397	3,489	4,098	0	0
Heating water (MJ)	15,759	24,789	23,843	24,419	35,129	53,117	12,592	14,663
Energy for fans (MJ)	0	0	0	0	0	0	3,245	4,011
Energy for lighting (MJ)	7,051	9,643	5,796	8,182	8,390	9,871	5,666	7,004
Summer comfort (MJ)	1,070	1,519	1,277	1,616	4,284	1,481	1,558	4,745
$Q_{total;EPC}$ (MJ)	171,129	165,291	93,321	156,105	156,806	136,508	61,431	70,908
EPC	2.66	1.78	1.83	2.18	2.10	1.73	1.29	1.15
Theoretical results EPA								
Energy for heating (MJ)	129,330	104,907	59,804	101,566	91,777	74,504	33,176	30,737
Additional energy (MJ)	1,138	4,558	814	1,242	1,260	1,397	1,811	2,110
Heating water (MJ)	18,509	16,705	16,505	15,402	13,932	12,562	19,478	24,289
Energy for lighting (MJ)	2,700	3,690	2,221	3,132	3,215	3,776	2,167	2,682
$Q_{total;EI\ old}$ (MJ)	151,677	129,860	79,343	121,342	110,184	92,240	56,632	59,818
EI old	1.11	0.70	0.87	0.95	0.86	0.84	0.85	0.62
Theoretical results ECW								
Energy for heating (MJ)	131,893	116,187	58,343	119,596	105,386	75,363	34,024	26,595
Additional energy (MJ)	2,915	3,527	2,088	3,181	3,230	3,580	4,647	5,413
Heating water (MJ)	11,946	18,481	12,912	12,805	12,805	13,185	12,805	13,718
Energy for lighting (MJ)	6,923	9,471	5,688	8,031	8,236	9,692	5,566	6,879
$Q_{total;ECW}$ (MJ)	153,677	147,666	79,031	143,613	129,657	101,820	57,042	52,605
EI_{new}	2.77	1.87	1.85	2.46	2.11	1.76	1.41	1.02
Label classification	F	D	D	F	E	D	C	A
Actual energy use								
Time period	April 2006 to August 2007	May 1997 to May 2007	October 1986 to October 2007	September 1999 to October 2007	June 1989 to May 2007	March 1998 to March 2007	October 2004 to June 2007	January 2003 to January 2007
Natural gas cons. (m^3)	2,663	34,346	36,185	17,003	33,858	13,923	1,769	4,018
Electric energy use (kWh)	7,695	57,564	69,038	34,460	37,500	38,923	6,570	7,491
$Q_{total;actual}$ (MJ) period	160,005	1,678,860	1,846,215	886,163	1,477,350	824,457	119,748	50,847
$Q_{total;actual}$ (MJ) annual	116,105	167,886	87,915	110,770	82,075	91,606	44,906	25,424

4. Financial performance of energy saving techniques

The financial benefits of energy saving techniques can traditionally be calculated with help of the electric energy price (in €/kWh), the natural gas price (in €/m^3) and the estimated or experienced electric and natural gas savings. However, it is already quite common to use Return On Investment (ROI) methodologies that take the increases in energy prices into account. The basic equation to calculate the ROI looks rather simple (e.g. [15]), but specifying the gains (G) and costs (C) of energy saving techniques in some detail is not an easy task. Life Cycle Costing (LCC) methods [16] take account of the environmental costs, demolition costs and recycling costs of buildings or measures in the calculations. The total gains of a project can be calculated by using the Net Present Value, which corrects the value of the gains in a specific year for the inflation and/or interest rate:

$$G = \sum_{a=0}^{n} \frac{G_a}{\prod_{y=0}^{a}(1 + r_y - i_y)} \tag{4}$$

In which:

- G: total of gains over a number (n) of years involved in the investment (€)
- r: interest rate (%)
- i: inflation rate (%)
- G_a: gains within a particular year (€/year).

However, when the electric energy and natural gas prices increase; the yearly gains should increase as well. These prices are strongly related with the oil price. Furthermore, caution should be paid to methodologies that provide a one-sided point of view by specifying these price increases without specifying currency inflation and interest rates.

An additional variable for the gains of energy saving techniques is presented in the form of the indirect benefits based on a value increase of the dwelling in which the product is installed. In general Dutch residential real estate is considered to be able to offer low risk investment opportunities. A green energy label will result in a better market price [3,4] and reduces the possible investment risks [4]. This offers an additional opportunity to assign these financial benefits to separate components of the buildings from the point of view that the value of the building is the sum of its parts. Vice versa value decrease of real estate can result in a lack of maintenance and a depreciation of applied energy saving measures, but even in this situation one may expect that the general value of houses with a green label will exceed the value of houses with a red energy label. To this end, the following formula is introduced:

$$G_a = \Delta q_{e;a} \times c_{e;a} + \Delta q_{g;a} \times c_{g;a} + \Delta V_a \times \frac{c_p + c_i - d}{V_a} \tag{5}$$

In which:

- G_a: gains due to energy saving and value increase within a particular year (€/year)
- $\Delta q_{e;a}$: change in electricity consumption (kWh/year)
- $c_{e;a}$: electricity price for domestic users in a particular year (€/kWh)
- $\Delta q_{g;a}$: change in natural gas consumption (m^3/year)
- $c_{g;a}$: natural gas price for domestic users in a particular year (€/m^3)
- ΔV_a: change in the value of the building in a particular year (€/year)
- c_p: initial investment costs of the energy saving product (€)

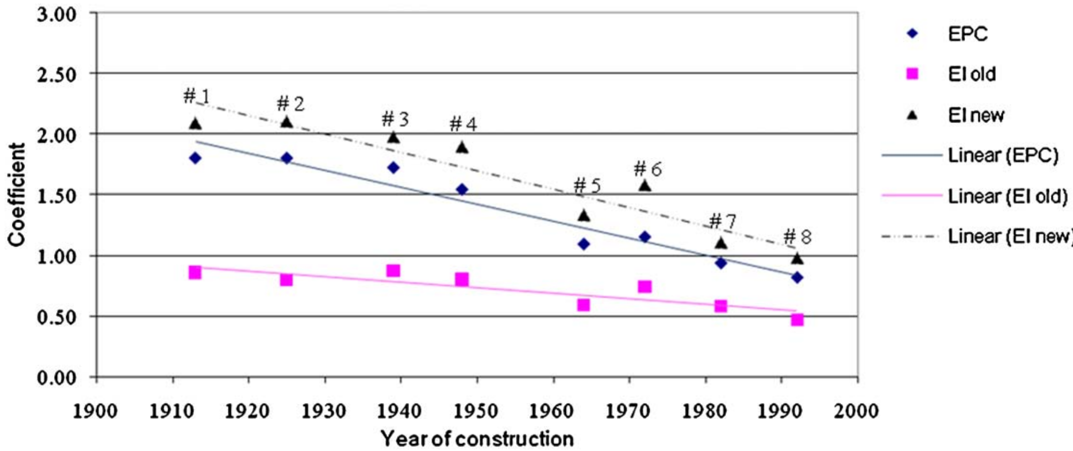


Fig. 5. Results per case study object on the energy performance based on the actual energy use.

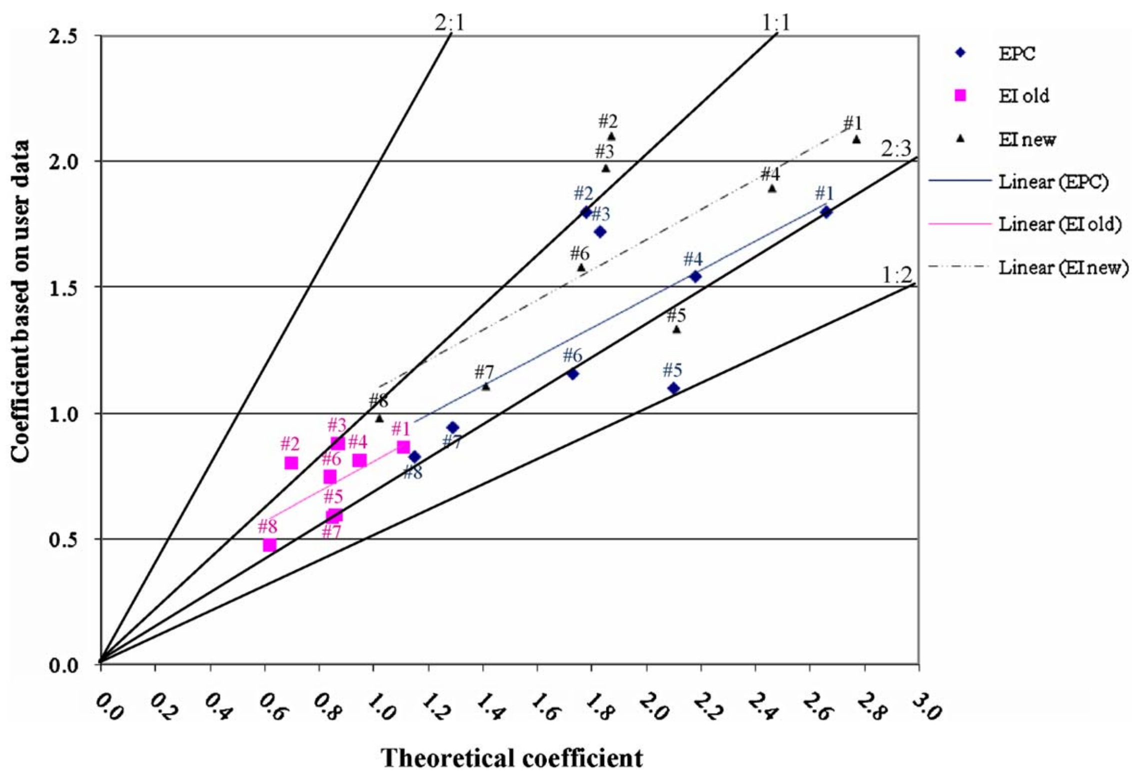


Fig. 6. Relations between the energy performance indicators based on theoretical assumptions and the actual energy use.

c_i: initial installation costs of the energy saving product (€)
d: total deprecation on the energy saving product based on life time expectancy (€)
V_a: value of the building at the time of installing the energy saving product (€).

Similarly to Eqs. (4) and (5) on the gains, an equation for the costs can be formulated:

$$C = (c_p + c_i) \cdot \prod_{y=0}^{n} (1 + r_y - i_y) + \sum_{a=0}^{n} \frac{c_{m;a}}{\prod_{y=0}^{a} (1 + r_y - i_y)} \quad (6)$$

In which:

c_p: initial investment costs of the energy saving product (€)
c_i: initial costs of installing the energy saving product (€)
$c_{m;a}$: maintenance costs in a particular year (€/year)
a, y: index of years
n: total number of years.

In this equation the removal costs of the energy saving product at the end of its lifetime are neglected. It is clear that the gains of energy saving techniques can be calculated more precisely after application and multiple years of use, than before investment and application. This was one reason to use a set of existing houses to get more insights in the financial benefits of energy saving technologies. Before analysing buildings and energy saving techniques financially, it is necessary to gain insights into the fluctuations of the most important variables regarding energy saving investments in dwellings. Hence, data of Statistics Netherlands [17] and the National Land Registry [18] was used to obtain information about long term fluctuations of inflation, interest rates, houses prices, natural gas prices and electricity

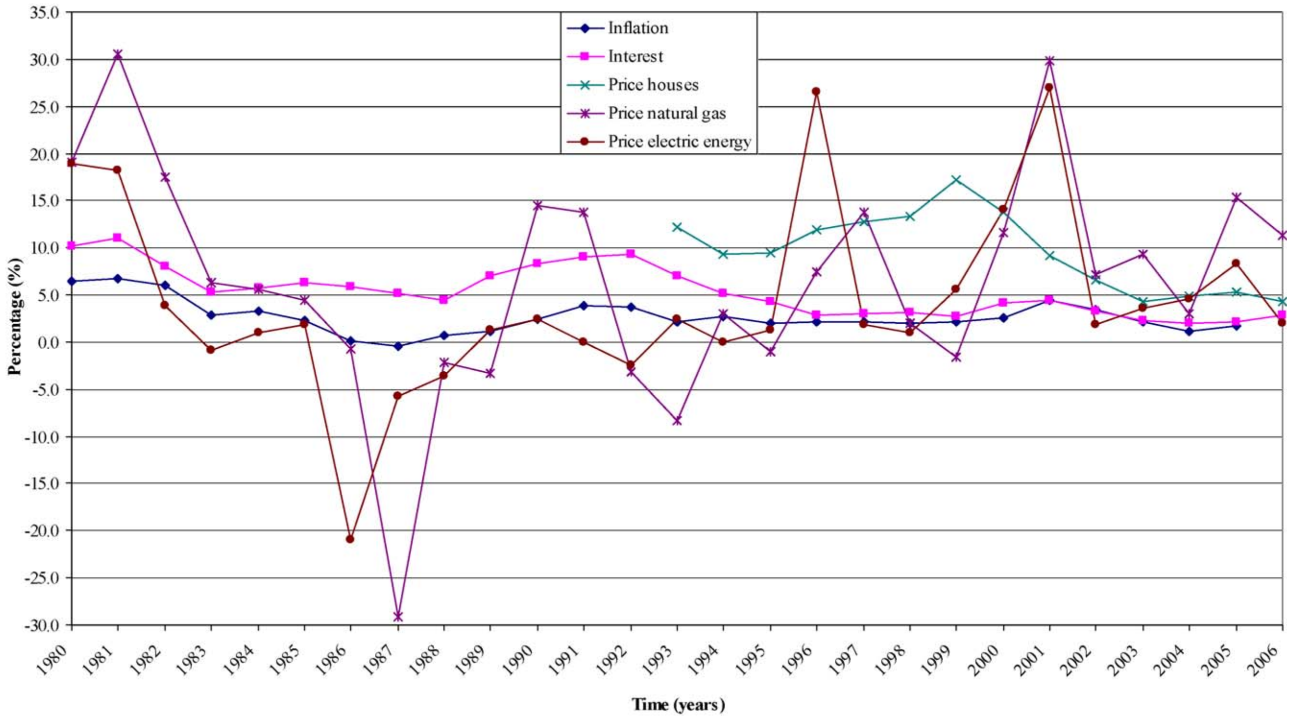


Fig. 7. Fluctuations in inflation rates, interest rates, the value of houses, and energy prices in the period 1980–2006. The percentages on the value of houses and energy prices are referring to the in- or decrease compared to the price value of the year before [17,18].

prices (see Fig. 7). Below we will shortly discuss our findings per topic.

1. *Inflation*: besides a small deflation in 1987 of 0.5%, the inflation rates vary from 0.7% to 6.7%. From 1983 up to 2000 the rates were rather stable with an average inflation of 2.1%. By Dutch standards the inflation rate for 2001 was quite high. Yet, with the introduction of the Euro in 2002 the inflation rate became lower again;
2. *Interest*: in the years that the inflation rates were relatively high, the interest rates were also relatively high. The last 12 years the interest rates were low to very low compared to former years, which might partially explain the increasing prices of houses. The interest minus inflation results in the effective interest, which valued from 0.11% to 5.90% (see Fig. 8);
3. *House price*: the value of dwellings in The Netherlands has increased significantly over the last few years, but it was not possible to give an overview for the entire past two decades. In the period 1993–2006 there were 6 years with a value increase of more than 10%. The inflation rate is partially depending on the value of dwellings, because their value influences the costs of living;
4. *Natural gas price*: in the Netherlands natural gas is commonly used to heat houses. Fig. 7 shows that the natural gas price had a larger variation than the former three variables over the past 20 years. The price of natural gas is strongly related to the oil price

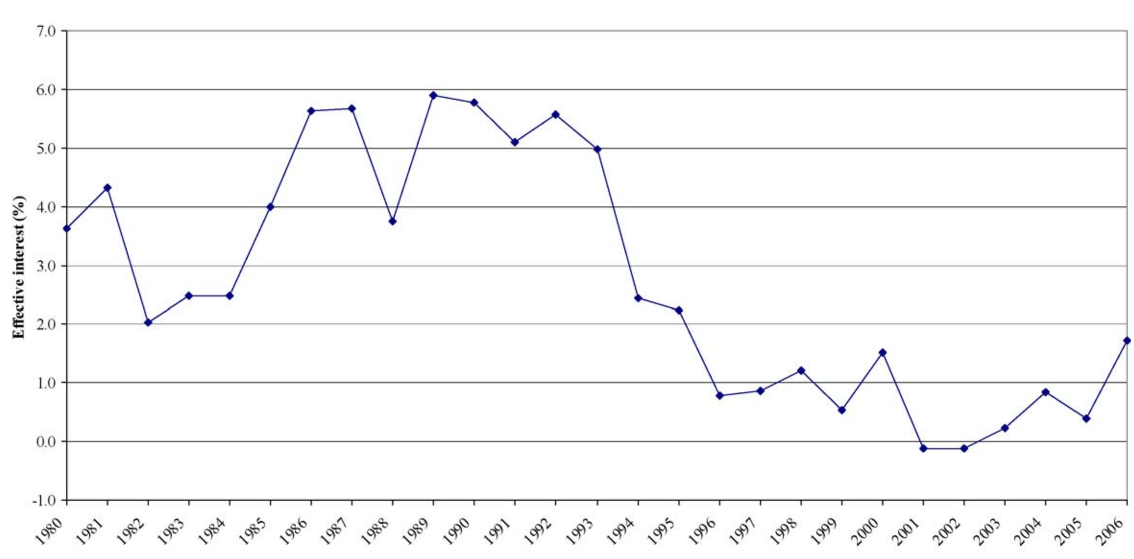


Fig. 8. Fluctuations in interest rates minus inflation rates [17].

and the consumer price also depends on the VAT rate and environmental taxes. The effect of these market-based instruments on the timing of applying energy saving measures has been discussed. However, the impact of environmental taxes and quotas have not stimulated firms in adopting new energy saving technologies [19];

5. *Electricity price*: the price of electric energy was fluctuating in the same way as the price of natural gas, because more than 60% of the electric energy production is based on natural gas [20]. The natural gas price is also linked to other fossil fuels (like coal and oil) needed for electricity generation. The introduction of additional environmental taxes in 1996 and 1997 had a strong impact on its price. The environmental taxes and VAT rate were significantly increased in the next 4 years, but these increases came almost to a hold in 2002.

5. Results of financial analyses

The figures on the inflation rate, interest rate, house prices, natural gas prices, and electric energy prices enable to reflect on the financial advantages of energy saving measures. This will be done by addressing two examples that were implemented in the houses within the case study:

1. The first example is roof insulation. This measure is applied to several houses. In our case we focus on house 6 from the year 1972;
2. The second example is related to house 3, built in 1939. It involves an extension at the rear of the house on ground level.

House 6 was equipped with roof insulation at the end of 1991. This roof insulation focuses mainly on energy saving, which was not the case of the preceding measure involving house 3. For the entire roof the thermal resistance of 1.58 m^2 K/W was improved to 2.22 m^2 K/W. Accordingly, the EPC was lowered from 1.90 to 1.73, the EI_{old} was lowered from 0.88 to 0.84 and the EI_{new} was lowered from 1.98 to 1.76 (both label D). The reduction on natural gas consumption -based on these EPC values- is estimated to be 416 m^3 per year and the increase in electric energy use is 41 kWh/year.

The initial investment costs were € 1460, but a subsidy on thermal insulation of € 438 was provided by the energy company. At the beginning of 1992 the value of the house was € 84,900. In 2006 the market value was € 324,000 [21]. Fig. 9 shows the costs and benefits of the installed roof insulation, and it can be seen that the payback period is 7 years. Reflecting on recent energy bills the actual energy consumption of the household (not including an electric external efficiency of 39%) is approximately 50% of the $Q_{total:EPC}$. This could mean that the energy consumption was actually lowered by 213 m^3 natural gas per year and the electricity use increased with 20.5 kWh per year. In this case the payback period using Eq. (5) will be 1 year longer, i.e. 8 years, but using the conventional method means that it will take even more than 15 years.

From a traditional energy perspective the roof insulation had a payback period of 10 years. This period can now be reduced to 7 years. Using formula 5 it had a Net Present Value of € 982, in 1992. By the end of 2006 the Net Present Value was € 1746.

At the beginning of 1996 house 3 was extended at the rear on the ground floor by an additional 16.4 m^2 floor space. Although the main reason was to gain space for the inhabitants, the improvement of thermal comfort was an important side effect. With exception of the ground floor the thermal resistance became 0.41–1.19 m^2 K/W for the walls and 0.16–1.19 m^2 K/W for the roof of the extension.

At that point the EPC improved from 2.85 to 2.07 (an EPC of 1.83 was reached by installing roof insulation later on). The EI_{old} was reduced from 1.09 to 0.95 and the EI_{new} was reduced from 2.67 (label F) to 2.09 (label E). Based on the EPC, this resulted in a theoretical natural gas reduction of 482 m^3/year and a theoretical increase in electric energy use (for lighting and ventilation) of 522 kWh/year. In 1997 the natural gas use and the electric energy consumption were reduced by 460 m^3/year and 500 kWh/year, respectively, which contradict our theoretical assumption that only the natural gas use would be reduced and the electric energy consumption would increase.

The costs of the project were approximately € 9100 and the value of the house after the alteration was € 46,740. The house, with a separate shed added in 1999, got a market value of € 118,000. In 2006 the value of the house was estimated at € 125,000, based on information of the Netherlands Association of Real Estate Agents [21]. The financial costs and benefits of this measure are visualised in Fig. 10. Although the extension of the house was not initiated to lower the energy costs, it is clear that the accumulated gains of the lower natural gas consumption rose to almost € 1500 over a time period of 9 years based on the computed EPCs. The overall benefits surpassed the costs after 2002. In theory the investment paid off in 2003, when the price of the house had already increased significantly. By the end of 2006 the Net Present Value of the investment was € 1178. The benefits derived from saving energy account for a large part of the total benefits in the situation of the roof insulation. The gains derived from the increasing value of the house 6 seem to be of less importance than within the case of the extension of house 3, because in the latter the financial benefits of energy reduction were relatively small compared to the value increase of the house. However, as long

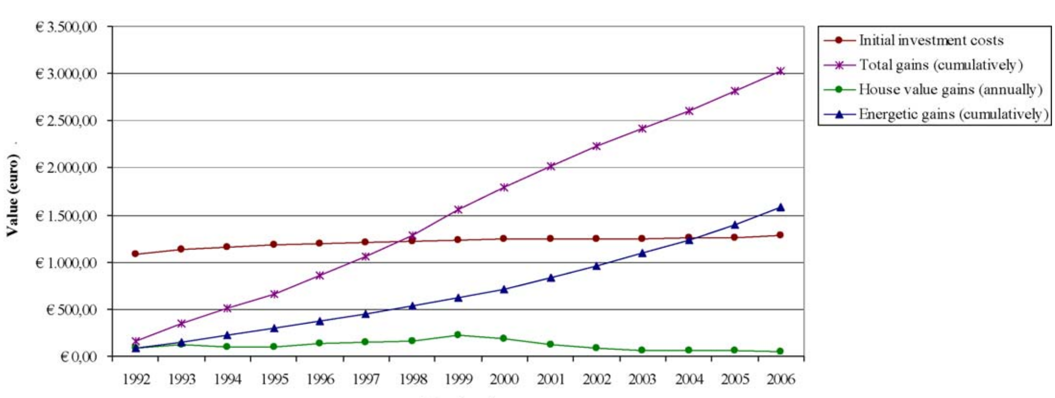


Fig. 9. Financial analysis of roof insulation on top of house 6.

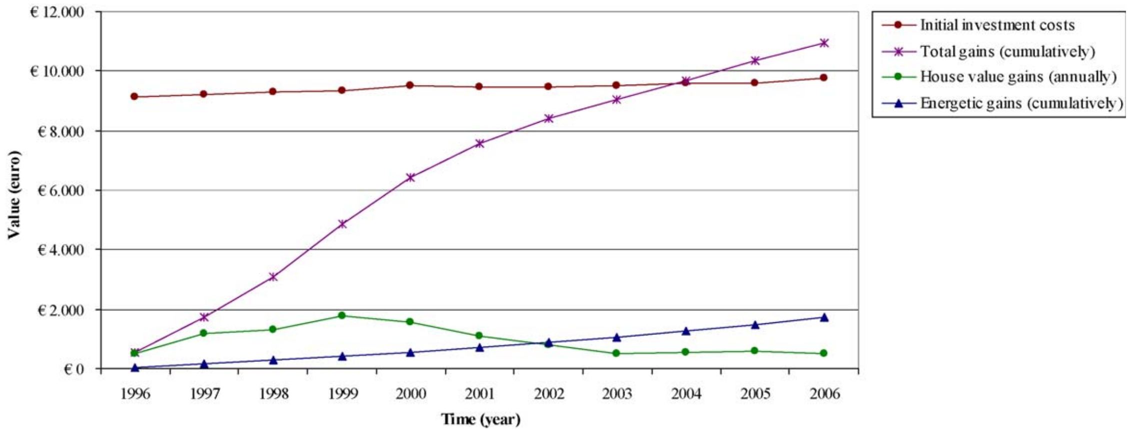


Fig. 10. Financial analyses of refurbishments within house 3.

as house prices are increasing the payback period of energy saving measures will be shortened. When house prices are decreasing the houses with a green energy label are still expected to have a higher value, because these houses can still provide the future owner relatively low energy costs. In future research the impact of the recent crisis can be more profoundly evaluated after the residential real estate market has resettled again.

6. Discussion and conclusions

In this paper three energy performance indicators were used to address the physical state of the building stock regarding its energy consumption.

(1) As expected the energy analysis of eight houses, constructed in different decades and representative for the energetic building related developments of last century, showed that in theory and practice the energy performance of new houses is in general better than the energy performance of old houses. The Dutch Building Code, constituted in 1992, only prescribes to these existing buildings a minimum thermal resistance for the building shell of 2.5 m^2 K/W, when a building license is required for refurbishments. It is not necessary to comply with regulations addressing the total energy performance of the object. This is one of the reasons why the energetic improvement of the existing building stock shows just little progress. However, the increased price of natural gas and past subsidies have already led to the application of some energy saving measures in the studied houses.
(2) Relating the estimated energy use of the houses to data on recent actual electric energy use and natural gas consumption, it is shown that the forecasted energy use derived by the three methods is, with only one exception, higher than the actual energy use. The $Q_{total;EI\ old}$ given by the EPA-methodology nears in most cases the actual energy use, but the relative difference still ranges from −25.5% to +29.3%. The energy consumption predicted by the EPC has the smallest standard deviation, especially when houses 2 and 3 are excluded. To estimate the actual primary energy consumption of existing houses based on the Q_{total} of one of the three energy performance indicators a correction factor of 67.2% or approximately 2/3 can be advised. Although our number of cases is limited, we have offered a methodology that can help to analyse more houses and houses in other maritime climates like The Netherlands.
(3) When using these performance indicators in computing the impact of energy saving techniques, one should, besides the 2/3 ratio consider an efficiency rate of 39% on the electric energy use. This rate expresses the Dutch efficiency of the electric power plant and power grid in general.

Regarding the financial aspect, we offered a way to calculate the financial appreciation of energy performance improvements of houses.

(1) The financial formula introduced a new variable to assign the general value increase of houses in the Netherlands partially to the particular installed energy saving measure. The underlying principle is that the value increase is a sum of benefits on the individual parts of a building. This also includes the installed energy saving measures.
(2) By presenting this variable the payback period of energy saving measures or improvements of the energy performance rates can be significantly reduced as long as the value of residential real estate increases. On the other hand, when residential real estate would devaluate, the user can only count on the gains received by the lower energy consumption caused by the measure. When energy saving is a side effect of the applied improvement, the introduced variable on the increasing value of real estate will contribute for a large part of the total gains.
(3) When saving energy or sustaining the energy supply is the main focus in altering a house, then the three performance indicators (EPC, EI_{old}, EI_{new}) as well as the energy performance certificate (related to EI_{new}) can be deployed to reveal the improvements. It remains however important to relate these estimations to the actual energy use of occupants. By using these assessment methods the appreciation of energy saving measures and therefore the willingness to pay for them could be enhanced. It was seen that the actual energy use is generally lower than the computed one, but the financial study learns that for the energy measures regarded here (namely refurbishment in combination with extending the living space and roof insulation) had much shorter payback periods, when the indirect benefits derived from the increased value of the dwelling are included.

The fact that the energy certificate, as part of the EPBD, has been introduced in 2008, offers great opportunities to study the importance of the energy use for consumers and their decision to acquire a particular object. By a better understanding of the financial challenges and opportunities of the existing building stock, a reduction in the consumption of fossil fuels is stimulated.

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