ANALYZING THE ECONOMIC FEASIBILITY OF PERMUTATIONS OF ENERGY-SAVING MEASURES WITH BATCH SIMULATIONS AND PARETO OPTIMIZATION

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ABSTRACT

Two years after the implementation of the Flemish energy performance regulation, the Flemish government has to consider the opportunities for strengthening the minimal energy performance requirements. In this frame, a technical-economical study on the cost-effectiveness of different energy-saving measures is executed for the residential sector, considering the current technologies and their costs.

For each measure, the characteristic parameters, the investment costs and the grey energy content are defined. Given the high correlation between the different measures, a simulation matrix of all possible and meaningful combinations is created.

The Flemish steady state EPBD calculation procedure is used to calculate the energy and environmental impact of the various combinations. The programme is adapted to perform a batch simulation with the defined simulation matrices. The economical evaluation is based on the total actual cost of each combination. The concept of Pareto optimization is used to determine the optimal trade-off between energy savings and costs.

The simulation results show that the economic optimal combination of energy saving measures, considering the costs and benefits over a long term of 30 years, can reach 30% better insulation level and a 40% better energy performance level than the current legal level. Depending on the adopted energy scenarios, even higher, economically viable, energy performance levels can be achieved.

INTRODUCTION

The Energy Performance of Buildings Directive of the European Parliament and Council (EPBD, 2003) was adopted on the 16th of December 2002 and came into force on the 4th of January 2003. The Directive is set to promote the improvement of the energy performance of buildings and to realise the savings potential in the building sector, which is estimated at 28% on average. January 4th 2006 was the official deadline by which the Member States had to transpose the Directive into national law.

On January 1st 2006, the Regional government of Flanders (Belgium) introduced her energy performance regulation. The procedures and the enforcement framework are established in the EPB Decree of December 22th 2006 (EPB, 2006). The requirements and the calculation methods are found in the EPB Decision of the Flemish Government of March 11th 2005 (EPB, 2005). This energy performance regulation applies to new constructions, renovations and extensions of buildings that require a building permit. It only applies to buildings in which energy is used for heating or cooling that meets human needs, such as dwellings, offices and schools. Requirements are set on four levels: the insulation level (maximum K-level and maximum U-values or minimum R-values), the energy performance level (maximum E-level), the level of indoor air quality and the level of summer comfort.

Article 9 of the EPB-Decree (EPB, 2006) states that "The Flemish Government will review, at least every two years, the method of calculating the energy performance of buildings, the procedures, the EPB requirements and the administrative burden of the regulation and adjust as appropriate". In order to reconsider the minimum energy performance requirements, a technical-economical study on the cost-effectiveness of different energy-saving measures is executed for the residential sector (Verbeeck G., Achten K., 2008). Aim of the study is to determine the economically feasible level for the energy performance requirements, considering the current technologies and their costs.

In the next chapters, the sequential steps of the study are presented. Firstly, referential dwellings and energy saving measures, as subjects of the study, are defined, followed by the simulation methodology and the applied economic and environmental parameters. Later, the Pareto optimization is explained and the main results of the study are presented. Finally, these results are discussed, the economic optimal energy performance requirements are defined and some barriers to implement a more strict energy performance regulation are revealed.

REFERENCE DWELLINGS

The Flemish building park is far from uniform or homogeneous. The differences in size, structure, shape and surroundings make it impossible to specify an exact average of the total residential building park. Based on a statistical analysis of the Flemish residential sector, common values in the real Flemish building park are defined and used to design seven referential dwellings. These fictitious dwellings are considered representative for the Flemish residential park.

For the new construction, a modern terraced dwelling, a semi-detached house, two individual dwellings, one typical and one modern, and two apartment buildings, one individual and one terraced, are considered. The reference situation is the current legal energy performance requirement (K45/E100). For the renovation, the same referential dwellings are used except for the individual apartment building. The modern terraced house is replaced by a more typical terraced dwelling. The non-insulated situation is considered as the reference case.

Table 1 gives an overview of the main characteristics of the reference buildings for new construction, Table 2 for renovation.

Table 1
Main characteristics for the reference buildings for new construction

NEW CONSTRUCTION	**TERRACED HOUSE (MODERN)**	**SEMI-DETACHED HOUSE**	**ISOLATED HOUSE (1)**	**ISOLATED HOUSE (2)**	**TERRACED APARTM.**	**ISOLATED APARTM.**
Heated volume	546 m³	523 m³	586 m³	613 m³	1753 m³	1201 m³
Heated floor area	134 m²	207 m²	187 m²	204 m²	572 m²	449 m²
Insulation level	K45	K45	K44	K45	K41	K40
Energy performance	E99	E96	E96	E98	E91/69/85	E97/102/95
Insulation						
Roof	10 cm MW	15 cm MW	15 cm MW	11 cm XPS	5 cm PUR	8 cm XPS
Facade	3 cm XPS	6 cm XPS	5 cm PUR	6 cm MW	3 cm XPS	7 cm MW
Floor	2 cm PUR	3 cm XPS	4 cm XPS	4 cm PUR	3 cm XPS	3 cm PUR
Glazing Frame	1.1 W/m²K Wood	1.1 W/m²K PVC	1.1 W/m²K PVC	1.1 W/m²K Alu, with thermal break	1.1 W/m²K Wood	1.1 W/m²K PVC
Ventilation	Natural	Natural	Natural	Natural	Natural	Natural
Space heating	Central, gas	Central, gas	Central, gas	Central, gas	Boiler per flat, gas	Boiler per flat, gas
Domestic hot water	On boiler	On boiler	On boiler	On boiler	Electrical, per flat	Electrical, per flat

Table 2
Main characteristics for the reference buildings for renovation

RENOVATION	**TERRACED HOUSE (TYPICAL)**	**SEMI-DETACHED HOUSE**	**ISOLATED HOUSE (1)**	**ISOLATED HOUSE (2)**	**TERRACED APARTM.**
Heated volume	452 m³	523 m³	586 m³	613 m³	1753 m³
Heated floor area	132 m²	207 m²	187 m²	204 m²	572 m²
Insulation level	K230	K187	K245	K241	K151
Energy performance	E357	E287	E428	E615	E451/209/210
Insulation	None	None	None	None	None
Glazing Frame	5.9W/m²K Wood	2.8 W/m²K PVC	2.8 W/m²K PVC	2.8 W/m²K Alu, without thermal break	5.9 W/m²K PVC
Ventilation	Natural	Natural	Natural	Natural	Natural
Space heating	Local, gas	Central, fuel	Central, gas	Central, gas	Boiler per flat, gas
Domestic hot water	Electrical tank	On boiler	On boiler	On boiler	Electrical, per flat

* MW = mineral wool (0.041 W/mK), XPS = extruded polystyrene (0.034 W/mK), PUR = polyurethane(0.028 W/mK)

* For apartment buildings, the K-level is calculated for the whole building, whereas the E-level is calculated per flat. The E-levels given are for the upper/middle/lower flats.

ENERGY SAVING MEASURES

Selection of the measures

The energy-saving measures are investigated on both the building envelope and the system.

Measures on the building envelope can be placement of additional insulation, better glazing, solar shading and improved air tightness. The compactness and thermal mass are not considered as separate parameters, but are contained in the choice of the reference buildings. These measures determine the net energy consumption.

The insulation thickness in the envelope components varies from a minimum, defined by the reference, to a maximum, depending on the envelope component. For roofs, a maximum insulation thickness of 32 cm can be applied, for the facade 20 cm and for the floor 10 cm. Thicknesses rise in 2 cm steps for the floor, 2.5 cm steps for the facade and 4 cm steps for the roofs.

Five different glazing types are considered with a U-value varying from 5.7 W/m²K to 0.6 W/m²K and a g-value from 0.76 to 0.42. The window frames remain those of the reference situation, except when replacing single glazing (U = 5.9 W/m²K) or when replacing aluminium frames without thermal break. For the variants with the highest insulation thickness, also passive house windows are considered ($U_{glazing}$ = 0.6 W/m²K, U_{frame} = 0.8 W/m²K)

Four different levels of air tightness are considered, ranging from the average of new built dwellings where no specific attention is paid to air tightness n_{50} = 1.5 + 10.5/compactness (SENVIVV, 1998), to the passive house standard for air tightness n_{50} = 0.6/h. The air tightness is related to the installed ventilation system. Only meaningful combinations are considered.

System-related measures have an impact on the final energy consumption and on the primary energy consumption. The simulated measures relate to space heating, domestic hot water production, ventilation and solar energy systems. All systems are considered in line with the current supply on the market.

The space heating system is mainly a central heating system with different energy carriers (gas, fuel). Only for the reference case of the renovated terraced house and for extremely well isolated variants, also a local heating is considered. For the central heating systems, there is a choice between high efficiency or condensing boilers on natural gas or fuel, or an electrically driven air/water or soil/water heat pump. The heat is emitted in the rooms by high or low temperature radiators or by floor heating, depending on the heating system. The room temperature can be controlled by a room thermostat or thermostatic valves, whereas the exit temperature of the water in the boiler can be fixed or variable.

For the domestic hot water production, both direct water heaters and storage tanks are considered. They are heated by gas or by electricity or connected to the heating boiler. Each of these systems can also be combined with a thermally active solar system. Per dwelling, only one solar collector system is considered: 4 m² for a single family house, installed on south oriented sloped roof (30° to 45°), and 8 to 16 m² for the apartment buildings, depending on the available roof area, installed on a frame according to the optimal slope and orientation.

Concerning the ventilation, starting point for the assumptions is a good design and execution, according to the current available technology. However, to avoid overestimation of the energy savings on ventilation losses, the most realistic options are selected, thus not always selecting the most energy saving option. The adopted ventilation systems are threefold: (1) a natural ventilation system with self-regulating grids type P3, (2) an extraction ventilation with natural supply through self-regulating grids type P3, and (3) a balanced mechanical ventilation system with a heat recovery of 70% efficiency and direct current fans.

All the above-mentioned combinations of energy saving measures are calculated with and without a solar photovoltaic (PV) system. Per dwelling, only one PV-system is considered. Depending on the available roof area, a system of 9 m² to 27 m², being 1.26 kWpeak to 3.0 kWpeak is provided on the single-family dwellings and 27 m² to 54 m² on the apartment buildings.

Characterization of the measures

For each measure, the characteristic parameters, the investment costs, and the grey energy content are defined.

The characteristic parameters are required for the energy performance calculations, such as insulation thickness, g-value, boiler efficiency, fan power, etc. These parameters can be interdependent, e.g. U-values and boiler power, and thus can be influenced by the combination of different measures.

The investment cost includes both material cost and workmanship. For renovations, the installation costs can differ from those for new construction, due to some installation restrictions. Where necessary, a destruction and dismantling cost is included. The life span of certain measures is less than the life span of the building. A reinvestment cost and, if necessary, a residual value is taken into account. The residual value is determined on a linear basis of the remaining life span. The construction of a cost database has been started already in earlier work on energy saving measures in buildings (Verbeeck G., Hens H., 2002). This database contains cost data for insulation materials, thermally better performing glazing types and window frames. These costs are updated and extended with cost data for ventilation grids, solar shading devices, air tightness measures and other system components.

The grey energy and emissions arise from the production of the applied materials and technical components. The data is based on the LCA database that was developed within the GBOU-project EL²EP (Verbeeck G., Hens H., 2007) and that is related to Ecoinvent2000 LCA database (Ecoinvent, 2004).

SIMULATION METHODOLOGY

Given the high correlation between the different measures, a simulation matrix of all possible and meaningful combinations is created.

In the first step, only the measures on the building envelop are considered. These measures have a longer life span and influence directly the net energy consumption and the dimensions of the technical installation. Pursuing a rational energy use, the first priority is to minimize the net energy consumption within the economic feasible limits, before optimizing the technical system. Depending on the referential building, all possible combinations of envelope-related energy saving measures result in 1050 (new isolated house) to 35720 (renovated terraced house) variations.

For every combination, several energy and environmental criteria are calculated. In the first step, these criteria are limited to:

- insulation level,
- net energy demand,
- risk for summery overheating,
- energy performance level,
- final energy consumption for heating, domestic hot water, auxiliary energy and (fictitious) cooling (based on the referential technical installations)
- embodied energy and CO_2 emissions,
- annual primary energy consumption and CO_2 emissions,
- annual primary energy savings and avoided CO_2 emissions.

All energy criteria are calculated with the steady state Flemish EPB-software (EPB, 2005). The calculation method is mainly based on the EN ISO 13790 (EN, 2004) and defines the yearly primary energy consumption via monthly averages. The EPBD-calculation takes into account the heat demand for space heating and sanitary hot water, the energy consumption of pumps and fans and the contribution of solar collectors, PV-panels or cogeneration. The electricity consumptions for household and lighting are not included. The climate data are monthly average values for the Test Reference Year of Brussels, Belgium. The programme is adapted to perform a batch simulation with the defined simulation matrices. The embodied energy is calculated with the life cycle inventory model, mentioned above (Verbeeck G., Van der Veken J., 2007).

Next to the energy criteria, different cost criteria are calculated. In the first step these cost criteria are limited to:

- initial additional investment cost,
- additional investment cost per m² heated floor,
- additional investment cost per m³ heated volume,
- annual energy cost.

Based on the Pareto-front (see below), determined for the objectives annual energy consumption (MJ) and additional investment cost (€), about 10 combinations are selected for each referential building, ranging from a minimum to a maximum annual energy consumption, and in each case complying with the legal requirements for K-level, E-level and maximum U-values.

In the second step, these most relevant combinations from the first step are combined with the system-related measures and a new simulation matrix is created. Depending on the referential building, the possible combinations of system-related energy saving measures result in 5400 (new modern apartment) to 13720 (new isolated house) variations.

The same energy, environmental and cost criteria as in the first step are calculated, extended with some life span calculations. Due to the very long life span of buildings, not the whole life span of the buildings is considered, but only the impact of one generation during 30 years.

- total primary energy consumption and CO_2 emissions over 30 years, including the embodied energy and emissions.
- total energy cost over 30 years,
- total investment cost over 30 years, including reinvestments and residual values,
- static payback and dynamic payback time,
- net present value,
- total present value
- internal rate of return
- cost per saved kWh primary energy and per avoided ton CO_2.

These indicators depend heavily on additional economical and ecological parameters. They are used as evaluation criteria in the Pareto-analysis, as explained below.

ECONOMIC AND ENVIRONMENTAL PARAMETERS

To calculate life span costs, the annual increase of investment costs, energy costs and the long term discount rate is taken into account.

In Belgium, the general inflation rate fluctuated around 2% for the last 15 years. This percentage is therefore applied as the annual increase of the investment costs.

The discount rate used in determining the present value of future cash flows. In case of energy saving investments in buildings, it determines whether money should be invested in buildings rather than in other economical sectors. For this study, the discount rate is based on the mean interest rate for August 2007 and set at 5.19%.

The assumptions for the energy prices are based on private consumer prices of December 2007. For electricity and natural gas, the adopted prices are those of Electrabel and SPE that represent 85% to 90% of the Flemish energy market (VREG, 2007). For fuel, the adopted price comes from the PetrolFed, the Belgian umbrella organisation of fuel distributors, and is valid for a purchase of more than 2000 litres of fuel. Table 3 presents the adopted energy prices in c€ per kWh for electricity, natural gas and fuel, including 21% VAT.

Table 3
Energy prices for electricity, natural gas and fuel (December 2007, incl. 21% VAT)

ELECTRICITY	NATURAL GAS	FUEL
14.52 c€/kWh	4.50 c€/kWh	5.65 c€/kWh

To define the annual increase of the energy cost, long-term projections have to be made on the energy prices. Because of the uncertainties, related to long-term projections, sensitivity analyses are performed in order to investigate the impact of the assumptions on the final results.

Four scenarios for the future energy prices are analysed in this study. All scenarios assume average annual linear increases of the energy prices (in %). The values are presented in Table 4.

Table 4
Scenarios for the energy prices for electricity, natural gas and fuel: mean annual linear increase of the energy price

	ELECTRICITY	NATURAL GAS	FUEL
Low	0.0%	0.0%	0.0%
Middle	1.87%	1.87%	1.48%
High	5.87%	5.87%	3.26%
Trend	10.0%	10.0%	8.15%

The middle and high scenarios for natural gas and fuel are based on long-term energy and emissions' projections for Belgium (Devogelaer D., Gusbin D., 2006). The scenarios for electricity are linked to those of natural gas, since electricity in Belgium is mainly produced by gas driven power plants. The low scenario is a very conservative one, as no increase of energy prices is assumed. The trend scenario is based on the outstanding price increase that occurred between 2000 and 2005. Although this scenario is assumed less probable, at the time of the study, the evolution of the energy prices during the last years seemed to maintain the strong increase.

To obtain an objective evaluation, none of the financial support mechanisms that currently exist in Flanders for energy saving measures, such as subsidies, fiscal depreciation and green certificates, is taken into account. In addition, the continued existence and the magnitude of the financial support is uncertain, since the policy on the financial support mechanisms is revised by the government on an annual basis.

The environmental impact is evaluated based on the total CO_2 emissions. The energy consumption is converted to the corresponding CO_2 emissions, considering the energy carrier. The applied factors were derived from the Flemish Energy Agency in 2007 (VEA) and are summarized in Table 5.

Table 5
Emission factors for electricity, natural gas and fuel (VEA, 2007)

ELECTRICITY	NATURAL GAS	FUEL
0.595 kg/kWh	0.201 kg/kWh	0.276 kg/kWh

PARETO ANALYSIS

The concept of Pareto optimization is used to determine the optimal trade-off between several objectives (energy, environmental and costs). In this evaluation, only 2-dimensional Pareto optimizations are performed, in search of the optimal solutions for two different criteria. A solution is optimal or part of the Pareto-front, if there is no other combination, among all calculated variants, that simultaneously performs better for both criteria. The interaction between two criteria can be visualised via the Pareto-front, which varies according to the considered criteria. Figure 1 shows a Pareto-front for the new-built semi-detached house

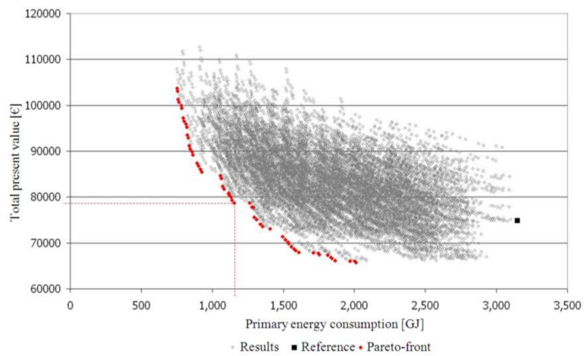

Figure 1 Pareto-front for the new-built semi-detached house

The total primary energy consumption and the total actual costs for various combinations of envelope-and system-related measures are shown. Each gray circle represents a particular set of measures, togheter a large cloud is dispersed. The black square indicates the reference case. The red cubes represent the optimal solutions or the Pareto-front.

Since the uncertainty on the parameters and the cost data influences the results, and since the magnitude of the uncertainty is unknown, a range around the Pareto front is analysed in order to end up with a variegated selection of the optimal solutions.

RESULTS

The results for the middle energy scenario are shown in Table 6 and Figure 2 for the new constructed dwellings and in Table 7 and Figure 3 for the renovated buildings. For each referential building, the total present value (TPV) as a percentage of the reference case, the additional investment cost (EI) in €/m² floor area and the static payback time (SPBT) in years can be found in the Tables. The Figures show the Pareto-front for the total present value in terms of total primary energy over 30 years and the related additional investment costs.

For the new constructed dwellings the economic optimal energy performance level (E-level) and insulation level (K-level) are presented together with the total present value, the additional investment cost and the static payback time that they represent. The economic optimum is the combination of measures that results in the minimum total present value.

For the renovated buildings, only legal requirements for the maximum U-value per renovated envelope component are imposed. Therefore, the economic optimal solutions for renovation are presented as optimal U-values for each envelope component.

Table 6

Overview of the total present value (TPV), the additional investment cost (EI) and the static payback time (SPBT) of the solutions on the Pareto front for the newly constructed referential buildings

NEW.	**TERRACED HOUSE (MODERN)**			**SEMI-DETACHED HOUSE**			**ISOLATED HOUSE (1)**			**ISOLATED HOUSE (2)**			**TERRACED APARTM**			**ISOLATED APARTM**		
Energy consump-tion [%]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]
100%	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0
80%	88	8	3	91	5	3	89	8	3	92	15	6	91	9	4	91	10	5
60%	84	35	7	91	35	12	87	35	8	89	50	12	93	50	15	86	45	11
40%	86	85	13	100	85	22	93	95	18	95	130	20	103	120	23	90	105	17
20%	97	190	20	136	230	43	106	180	35	105	220	25	116	200	31	109	215	27
Economic optimum	84	63	11	90	15	7	85	18	6	89	48	11	90	11	6	86	53	11
	E55 / K31			E66 / K41			E61 / K38			E61 / K39			E63 / K37			E63 / K34		

Table 7

Overview of the total present value (TPV), the additional investment cost (EI) and the static payback time (SPBT) of the solutions on the Pareto front for the renovated referential buildings

RENO-VATED	**TERRACED HOUSE (TYPICAL)**			**SEMI-DETACHED HOUSE**			**ISOLATED HOUSE (1)**			**ISOLATED HOUSE (2)**			**TERRACED APARTM**		
Energy consump-tion [%]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]	TPV [%]	EI [€/m²]	SPBT [y]
100%	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0
80%	86	30	2	84	15	2	82	20	1	82	25	1	85	20	2.5
60%	73	60	4	67	30	4	64	30	1.5	64	55	2	69	45	4.5
40%	60	90	6	53	60	5	47	60	2.5	47	100	2.5	54	70	5.5
20%	51	155	9	-	-	-	33	120	4	31	185	3.5	52	160	10
	Economic optimal U-value (W/m²K)														
Slope roof	0.19			0.22			0.19			-			-		
Flat roof	0.25			-			-			0.24			0.29		
Facade	0.27			0.27			0.26			0.21			0.23		
Floor	0.29			0.26			0.30			0.31			0.38		
Staircase	-			-			-			-			0.25		

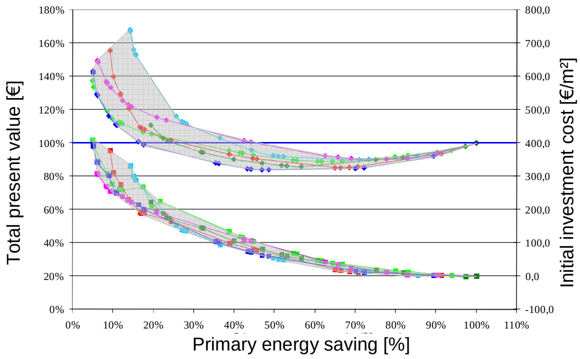

Figure 2 Pareto-front for the new-built referential buildings

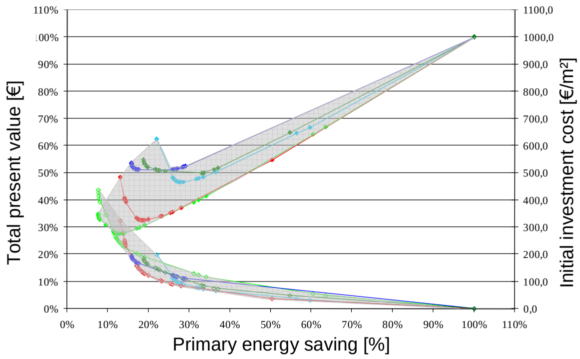

Figure 3 Pareto-front for the renovated referential buildings

DISCUSSION

Each of the results in Table 6 and 7 represents a certain combination of energy saving measures. They will be discussed here separately for new constructed and renovated dwellings. The results are valid for the middle energy scenario. When assuming the high and trend scenario, the total present value of the economic optimum decreases and more energy saving measures become economically viable. The economic optimum, however, remains representing the same optimal combination of energy saving measures. These results confirm conclusions of earlier studies (Verbeeck G., Hens H., 2002 & De Coninck R., Verbeeck G., 2005), namely that the economic optimum, being the combination of energy saving measures that results in the lowest total present value, is independent of the adopted energy scenario.

The simulations were performed with a steady state model via monthly average weather data, nevertheless they show similarity to the result adopted by a transient hourly model (Verbeeck G, Hens H., 2007).

New construction

As mentioned, the reference for all new buildings is the current legal energy performance regulation, being an energy performance level E100 and an insulation level K45.

Small measures, such as the application of an outdoor sensor to control the water temperature for space heating or by installing a storage tank on gas instead of electricity, can realise small reductions of the primary energy consumption (ca. 10%), compared to the reference, at a limited additional investment cost (< 5 €/m²).

Improving the insulation level to ca. K40 and installing a condensing boiler instead of a high efficiency boiler can realise reductions up to 20%. The additional investment cost for this combination of measures is 5 to 15 €/m², depending on the reference dwelling.

Further improving the insulation level to ca. K35 and improving the air tightness of the building can realise higher reductions of 30 to 40%. These measures, in combination with a condensing boiler, represent an additional investment cost of 35 to 50 €/m².

By further extending the insulation level, applying a mechanical ventilation system with heat recovery or by installing a heat pump, a solar collector or a PV-system, further reductions of the primary energy consumption are possible. Combining these measures, results in primary energy reductions of 70% and more, compared to the current legal level. However, as can be seen from Table 6, this represents an additional investment cost of more than 100 €/m² and is not economically viable within 30 years (TPV > 100%) for most of the reference buildings.

The economic optimum consists of an insulation level of K36.7±3.6 and an energy performance level of E61.5±3.7. This optimum is mainly realised by combining the economic optimal insulation level with a good air tightness, a well-designed extraction ventilation system and a condensing boiler with an outdoor sensor. Compared to the current legal level, this optimum represents an average energy saving of 35 to 40% and over a period of 30 years, this optimum is 10 to 15% cheaper than the reference case.

Renovation

Comparing Figure 2 and Figure 3, it is obvious that the energy saving potential for renovation is much larger than for new construction.

The additional investment cost for small reductions of the energy consumption (10 to 20%) is larger for renovation (10 to 30 €/m²) than for new construction (5 to 10 €/m²). However, the energy savings in absolute values are much larger, which means the payback time of renovation investments is much smaller, in most cases even less than 1 year.

In contrary to new construction, large reductions of the primary energy consumption (± 70%) are still economically viable, with a total present value of less than 40% of the reference case.

On an average for the different reference dwellings, the economic insulation optimum lies at U = 0.25 to 0.30 W/m²K for each envelope component. For windows, this optimum is less obvious. Due to high investment cost, the replacement of windows is only useful from an economic point of view if all other envelope components are already insulated. However, in practice, it often is easier to replace windows than to insulate the facade or the floor and the gain in thermal comfort can be significant.

CONCLUSION

The study shows that there is a clear potential for a more stringent energy performance regulation in Flanders within economic acceptable bounds.

For new buildings, the current legal requirements (E100 and K45) are much more inefficient than the economic optimum, being an energy performance level of E55 to E65 and an insulation level of K30 to K40. Compared to the referential dwellings, the average energy saving potential for this optimum is 35 to 40% and the average economic saving over a life span of 30 years reaches 15%.

For renovation, the energy saving potential is even larger than for new buildings. However, it is far more difficult to concretise it in legal requirements, since the boundary conditions for renovation are generally more restricted. The energy performance regulation takes into account these restrictions by not imposing global requirements for the energy performance level or insulation level, but by imposing requirements per envelope component. This study shows that the maximum U-values for renovation can cope with the U-values of the economic optimum for new buildings, being a U-value of 0.25 to 0.30 W/m²K instead of 0.40 to 0.60 W/m²K in the current regulation.

In theory, people naturally aim at economic optimal solutions. However, in practice, this optimum often is difficult to determine and for most people, the additional initial investment cost is the largest barrier to implement this optimal combination of energy saving measures.

Since energy efficiency is not only a priority of the individual family due to economic reasons, but certainly also a societal priority due to economic and ecological reasons, The government has an important role in providing good mechanisms for financial support to encourage energy efficient new constructions and renovations. This way, the economic optimum, determined in this study, could be set as the minimum legal requirement on a longer term. The term to reach this target should be adapted to the evolution of the market and in the society.

In fact, the minimum requirements can be beyond the economic optimum, as the purpose of this legislation is not to reach the economic optimum, but to come to lower energy consumptions, reduced CO_2 emissions and improved comfort. The importance of a solid financial support and well-researched information campaigns is than even greater.

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