554: The economics of extremely low energy dwellings: how far can we go?

Griet Verbeeck [1]*, Hugo Hens[2], Kristien Achten[3]

Department of Architecture, University College of the Province of Limburg, Diepenbeek, Belgium[1]*
Gverbeeck2@mail.phl.be
Laboratory of Building Physics, Katholieke Universiteit Leuven, Heverlee, Belgium[2]
Engineering office 3E, Brussels, Belgium[3]

Abstract

Extremely low energy dwellings are developed by the need for more sustainability in the residential sector. It is clear that this sustainability can only be accomplished if many conditions are fulfilled. This paper confronts the results of two research projects that analysed the need for more sustainability in dwellings in Belgium from two different points of view. The first research project analysed the environmental impact and financial cost of extremely low energy dwellings from the point of view of a building owner. The results showed that this kind of dwellings effectively can be realised, but only at a high investment cost. The second research project analysed the changes needed in the Belgian energy policy to achieve a CO_2 reduction of 20% by 2020 for the building sector. This project showed the need for more severe energy performance requirements and a higher grade of renovation. However, as the first project showed, there is a substantial financial barrier to achieve this goal. A more constant policy of financial support is therefore indispensable to avoid that sustainable houses remain limited to a minor part of environmentally conscious consumers, willing to invest a large budget in an extremely low energy house.

Keywords: sustainable building, building stock, energy performance, costs

1. Introduction

The main driving force for the development of extremely low energy dwellings is the need for more sustainability in the residential sector. In the existing Belgian building stock around 180 kWh/(m²,a) of end energy is used for heating, domestic hot water, electrical appliances and lighting. Some legislative initiatives have already been taken to improve the energy efficiency in buildings, such as the insulation standard since 1992 and the energy performance regulation since 2006. However, buildings that meet these requirements only reduce the final energy use for heating to 100 kWh/(m²,a). This means that there still is a large potential for sustainability in the Belgian residential sector.

One of the current national and international trends concerns the development of extremely low energy dwellings, ranging from passive houses [1-3] over zero energy houses [4-6] to energy autarkic buildings. These concepts tend to be considered as the ultimate objective for sustainable buildings [4]. Though, in contrast with traditional buildings, these approaches assume the application of a good many technologies resulting in much more costs to construct these buildings. And although these buildings have much smaller energy consumption during the usage phase, the projects hardly ever show clearly if the global balance of energy and costs is finally positive from the point of view of the building owner [7].

On the other hand, from the point of view of society, large efforts are indispensable to counter further global climate change and depletion of the fossil fuels supplies. For Belgium, the Kyoto Protocol imposed a CO_2 reduction of 7.5% between 1990 and 2012, whereas the EU Energy Summit of January 2008 decided to reduce the EU emissions with 20% by 2020 and to provide 20% of the EU's overall energy consumption through renewables by 2020.

In this frame, this paper will confront the results of two research projects that analysed the impact of the need for more sustainability in dwellings in Belgium from two different point of views. Firstly, the two research projects are shortly described. Then the main results of both projects are discussed and finally confronted to each other in order to identify some of the barriers that have to be countered in order to achieve more sustainability in the residential sector.

2. Economic evaluation of extremely low energy dwellings

2.1 Context

The first research project (EL²EP-project) concerns an in-depth evaluation of the environmental impact and financial cost during the whole life cycle of the building and its installations. By coupling LCA and cost assessment with advanced optimization techniques, concepts for globally optimized extremely low energy buildings are developed within this project [8].

2.2 Methodology

2.2.1 Reference buildings and energy saving measures

The objects for optimization are five residential buildings, designed following the statistical average of the Belgian residential sector. The non-insulated version of these reference dwellings is taken as a starting point. The parameters for optimization are related to energy saving measures applied to both the building envelope and the heating and ventilation systems. The optimization itself is performed in two steps. In the first step only envelope-related energy saving measures are considered, such as insulation for the roofs, attic floor, façade and ground floor, glazing and window frames, and air tightness. In the second step, the measures on the building envelope are combined with system-related measures, including systems for heating, ventilation, local electricity production and control. Not only traditional systems are considered, but also more innovative technologies, such as heat pumps, cogeneration of heat and power, mechanical ventilation with heat recovery and air-heating and renewable solar energy systems.

2.2.2 Evaluation models for energy and costs

The energy impact of the building concepts is evaluated through a life cycle inventory of primary energy flows and greenhouse gas emissions. As the optimisation process aims at developing building concepts that are globally optimised and at the same time satisfy the boundary conditions for thermal comfort, indoor air quality, etc., according to the overall performance matrix of the IEA Annex 32 [9], the LCI does not focus on materials or building components, but considers the building as a whole. Due to the very long lifespan of buildings however, not the whole life span of the buildings is considered, but only the impact of one generation during 30 years. Details on the life cycle inventory model developed in this project can be found in [10].

To evaluate the economic impact of the building concepts from the point of view of a building owner, a cost database and a cost evaluation model is established to be integrated in the optimisation model.

The cost database contains not only cost data for materials that improve the thermal quality of the building envelope, such as insulation materials, thermally better performing glazing and window frames, but also for all kinds of materials applied in the building envelope, such as bricks, ventilation grids, solar shading devices, wood frame constructions, etc. These costs are mainly based on price offers by building contractors for the reference buildings of the project. The price offers comprised the working hour cost. With these data, a cost database has been created by which the overall construction cost of a building can be calculated.

The cost data for system components are also based on price information for boilers, radiators, floor heating systems, storage tanks, fans, pipes, etc. However, as the insulation level of a building directly affects the needed power and the dimensions of the heating system, the cost is expressed as a function of the insulation level.

The assumptions for the energy prices are based on the private consumer prices for natural gas, fuel and electricity of May 2006 [11,12]. Table 1 presents the energy prices adopted. These prices are overall prices, including all taxes.

Table 1: Energy prices for gas, electricity and fuel in c€/kWh

Energy prices May 2006	**Proportional term (c€/kWh)**	**Fixed term (€/year)**
Natural gas for heating	4.64	103.46
Fuel	5.77	-
Electricity		
Twofold day price	18.33	40.40
Twofold night price	9.64	
Exclusive night price	7.91	17.73

In order to take into account the uncertainty on the energy price evolution, three different scenarios are considered for the price evolution of gas, fuel and electricity: a low, medium and high scenario. The values for the medium and high scenario are based on the EU POLES scenarios from 2000 until 2030 for gas and fuel [13]. The values are presented in table 2. However, only the growth factors of the EU POLES scenarios are adopted. The starting values are those of May 2006.

The cost database and the energy price scenarios form the input for the cost evaluation model. In this cost-benefit analysis, a large number of economic criteria is calculated, but in the optimisation process only the total present value and net present value are chosen as cost objectives to be optimised.

Table 2: Three scenarios for energy price evolution for natural gas, fuel and electricity

Energy carrier	**Low (% per yr)**	**Medium (% per yr)**	**High (% per yr)**
Natural gas	0	2.1	4.3
Fuel	0	1.9	3.2
Electricity	0	2.1	4.3

All results presented below in chapter 4 have been calculated for a discount rate of 4%, as this is assumed to be a realistic estimation of the real interest rate. However, in order to control the robustness of the results with relation to the assumptions, also different scenarios for the discount rate have been analysed: 2%, 4% and 8%. For clarity's sake, subsidies and fiscal depreciation are not taken into account in this project, as this financial support is changing from year to year.

2.3 Passive houses and zero energy houses

2.3.1 Economic optimal building concept

As the results of the EL²EP-project presented in chapter 4 will show, an economic optimal combination of energy saving measures can be deduced with the methodology described above. This economic optimum represents a low energy building concept with a good insulation level (U_{mean} = 0.3-0.35 W/m²K) combined with a condensing boiler, a good air tightness and a natural ventilation system. Most importantly this economic optimum appeared to be independent of the scenarios adopted for energy price and discount rate.

2.3.2 Passive houses

In order to compare the economic viability of passive houses with the economic optimum, the passive house standard is applied to one reference dwelling, being the terraced house as it is the building with the highest compactness. The traditional heating system is replaced by an electrical air heater integrated in the mechanical ventilation system with heat recovery. Building simulations are performed with the dynamic system simulation program TRNSYS 15 [14].

2.3.3 Zero energy houses

Also for zero energy houses the economic viability is compared to the economic optimum. Starting point are the passive house variants of the terraced dwelling, with an annual end energy consumption for heating of 1425 kWh/a to 1551 kWh/a. As the energy production in a zero energy house not only has to cover the energy consumption for heating, but also for hot water, lighting and electrical appliances, this energy consumption is determined with calculation modules based on in situ measurements [15]. Depending on the magnitude of the households, the number of appliances present and their energy efficiency, the energy consumption for domestic hot water, lighting and electrical appliances ranges from 2000 to 3900 kWh/a in the zero energy houses. Also the extra investment cost for the energy efficient appliances is taken into account in the cost-benefit analysis, based on consumer prices [16].

For the energy production, both thermal solar collectors and photovoltaic modules are considered and the most optimal configuration of solar collectors and PV-modules is determined. For the contribution of thermal solar collectors, calculations are performed for collector areas of 4m² up to 20m². For the contribution of photovoltaic modules, a PV-calculation module is used that has been developed within the project [17]. This calculation module contains data on 169 different PV-types and 176 different invertors and chooses the best PV-type, taking into account the roof surface and the exact location of roof windows. Also the investment cost is calculated as well as the green current certificates, the electricity cost saving (based on 0.15€/kWh) and the net present value over the life span of the PV modules (25 years).

The comparison between the economic optimum and the developed concepts for passive and zero energy houses is presented in chapter 4. However, it already can be mentioned that from the point of view of a private building owner both the passive and the zero energy houses do not appear to be economically viable within a period of 30 years, due to the high investment cost.

3. CO_2 emission reduction in the Belgium building stock

3.1 Context

In order to prepare the post-Kyoto era, the EU Energy Summit of March 2007 proposed an ambitious action plan to reduce the EU emissions with 20% by 2020 and to provide 20% of the EU's overall energy consumption through renewables by 2020. In the frame of this preliminary agreement on energy and climate change, a consortium of building companies ordered a study on the CO_2 reduction options in the Belgian building stock. Aim of the study was to determine the developments needed in the Belgian residential sector to effectively achieve a CO_2 emission reduction of 20% by 2020, compared to the reference year 1990.

3.2 Methodology

3.2.1 CO_2 balance for the present situation

Firstly, a detailed CO_2 balance of the Belgian residential sector is established for the years 1990, 2000 and 2005, based on available statistical data of the composition of the Belgian building stock and the related overall energy consumption and CO_2 emissions. For the years 1990 and 2000, the databases of the Belgian National Institute for Statistics (NIS) contain overall information on the building stock, characterised by age, type, total floor area, heating system and energy carrier. For the year 2005, only less detailed information on age, type of buildings and number of building permits is available from ECODATA [18]. The methodological starting point for this balance is the bottom-up model for the Belgian building stock established by [17], however adapted to the current EPBD and with integration of renewable energy systems. In this bottom-up model a set of simple quadratic dwellings with one, two or three floors is constructed that substitute the overall set of real dwellings. Age is translated into U-values, air tightness and efficiency of the heating system. The energy consumption for heating, domestic hot water and ventilation is calculated with the Flemish version of the EPBD, the electricity consumption for lighting and electrical appliances is calculated with the module developed in [15].

The bottom-up model is further fine-tuned, so the overall energy consumption and CO_2 emissions calculated with this model corresponds with the available overall data on energy consumption and CO_2 emission from the Energy Balances of Flanders, Wallonia and the Brussels Capital Region. In this way, the real situation in 2005 and the evolution between 1990 and 2005 can be explored.

3.2.2 Business as usual scenario for 2020

In order to have a reference the reduction scenarios can be compared with, a business as usual (BAU) scenario is deduced for the year 2020. This BAU scenario assumes no changes in the energy performance regulation and incorporates scenarios for the evolution of the households and the construction and renovation activities, based on Belgian demographic and energy perspectives for 2030-2050 [19, 20]. Figure 1 presents the evolution of the CO_2 emissions from dwellings between 1990 and 2020 for the BAU scenario, subdivided by year of construction. The last bar at the right represents dwellings, renovated between 2005 and 2020, according to the current energy performance regulation.

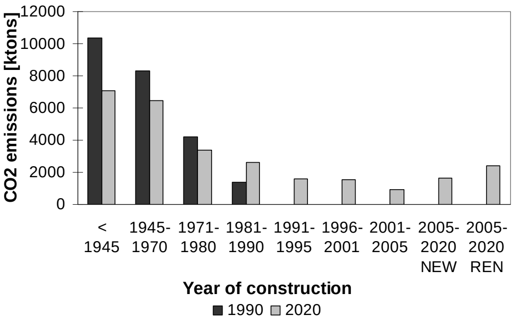

Fig 1. Evolution of CO_2 emissions from dwellings between 1990 and 2020, per year of construction

3.2.2 CO_2 reduction scenarios

From the analysis of the evolution between 1990 and 2005, two main priorities for CO_2 reduction can be deduced. One priority is a more severe energy performance regulation in order to reduce the CO_2 emissions of new and renovated dwellings. The second priority is a much higher renovation grade in order to strongly upgrade the energy performance of the whole building stock.

So, with the BAU-scenario as a starting point, three groups of reduction scenarios are analysed. The first group comprises scenarios to improve the energy performance of new and renovated dwellings. Table 3 presents the adopted U-values and heating systems for all energy performance scenarios for new dwellings, table 4 the adopted values for renovated dwellings.

The second group of scenarios considers different renovation grades: from renovating 11% of the building stock between 2005 and 2020 (BAU) over 25% and 50% up to 75%. Two extra scenarios are considered assuming purposive renovation of dwellings built before 1970. All renovations are assumed to be with building permit and thus according to the energy performance regulation. Apart from that, also renovation actions that need no building permit are considered, such as replacement of the boiler, replacement of the windows or installation of roof insulation.

Table 3: Adopted U-values and heating systems for the energy performance scenarios for new dwellings

Scenarios	**BAU**	**PRES1**	**PRES2**
U-values [W/m²K]			
Roof	0.40	0.15	0.15
Façade	0.60	0.35	0.15
Floor	0.40	0.30	0.15
Glazing	1.1	1.0	0.8
Frames	3.3	3.0	0.8
Heating			
Gas	50% cond, 50% HE*	100% cond	100% cond
Fuel	20% cond, 80% HE*	50% cond, 50% HE*	100% cond
Heat pump	-	25%	50%

* HE= high efficiency boiler

Table 4: Adopted U-values and heating systems for the energy performance scenarios for renovated dwellings

Scenarios	**BAU**	**PRES1**	**PRES2**
U-values [W/m²K]			
Roof	0.40	0.20	0.15
Façade	-	50% 0.35, 50% -	0.35
Floor	-	50% 0.30, 50% -	0.30
Glazing	1.1	1.0	0.8
Frames	3.3	3.0	0.8
Heating			
Gas	50% cond, 50% HE*	100% cond	100% cond
Fuel	20% cond, 80% HE*	50% cond, 50% HE*	100% cond
Heat pump	-	25%	50%

* HE= high efficiency boiler

The third group of scenarios is related to an increasing application of solar energy systems, both thermal collectors and PV-modules, from BAU (0.1%) over 25% and 50% up to 100%.

All scenarios are calculated both separately and mutually combined, and are compared with the BAU-scenario. In all scenarios, the rebound effect caused by energy saving measures is taken into account in the calculation of energy consumption by relating the mean indoor temperature to the age of the building, according to [17].

The results of the analysis of the CO_2 reduction scenarios are presented in next chapter, after the presentation of the results of the economic evaluation of extremely low energy houses.

4. Results of both projects

4.1 Results for the economic evaluation of extremely low energy houses

Table 5 presents the extra investment cost per m² floor area for the building envelope and the systems for heating, ventilation and renewable energy for the economically optimal variant, the passive variant and the zero energy variant of the terraced house. For the latter, 6m² of solar collectors and 31m² of PV modules are needed to transform the passive variant into a zero energy variant and thus, to cover the overall yearly energy consumption of the dwelling (heating, ventilation, lighting, hot water and electrical appliances).

Table 5: Extra investment cost per m² floor area for the building envelope and the systems for heating, ventilation and renewable energy for the economic optimal variant, the passive variant and the zero energy variant of the terraced house.

Extra investment cost [€/m²]	**Economic optimum**	**Passive house**	**Zero energy house**
Building envelope	140	245	245
Systems for heating and ventilation	-20	-30	-30
Renewable energy systems	0	0	310
Total extra investment cost	120	215	525

The economic optimum is very robust, i.e. this economically optimal combination of energy saving measures remains the same, regardless of the adopted scenario for energy price and/or discount rate. Moreover, even for the very conservative scenario that assumes no further increase of the energy prices for 30 years, this optimum is economically viable.

Passive houses on the contrary, become economically viable only at higher energy prices than assumed in this project. For zero energy houses to become viable, even higher energy prices are needed.

However, the largest barrier for these extremely low energy houses is the very high initial investment cost. For a dwelling with a floor area of 150 – 200m², the passive variant will be 15.000 to 19.000€ more expensive than the economic optimum. The zero energy variant will even be 60.000 to 80.000€ more expensive than the economic optimum. So, without any substantial financial support from the government, these extremely low energy houses will remain limited to a minor part of consumers with a high environmental consciousness that is willing to invest such a large budget in an extremely energy saving house.

4.2 Results for the scenarios for CO_2 reduction in the overall building stock

As in the reference year 1990, ca. 25 Mtons CO_2 were emitted by the Belgian building stock, the goal for 2020 is an emission of max. 20 Mtons. Analysis of the results clearly showed that none of the adopted scenarios is able to reduce the CO_2 emissions significantly, if applied as a single policy measure. Figure 2 shows the impact of the energy performance scenarios on the overall CO_2 emissions and figure 3 the impact of the renovation scenarios. Without changing the policy on energy performance or renovation (BAU), the CO_2 emissions in 2020 will be 14% higher than in 1990. However, as figure 2 shows, by only improving the energy performance of new and renovated buildings, a CO_2 reduction down to the level of 1990 can barely be achieved, even less a reduction of 20%. The same conclusion is valid for the renovation scenarios (figure 3): even when renovating 75% of all dwellings by 2020 according to the current energy performance regulation, the CO_2 emissions will only be slightly below the reference level of 1990, being 25 Mtons.

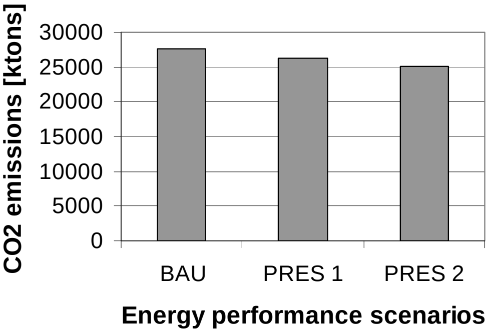

Fig 2. Impact of the energy performance scenarios on the overall CO_2 emissions

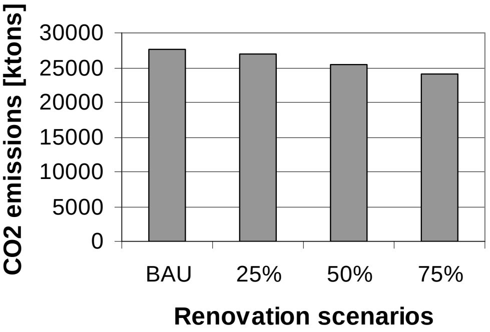

Fig 3. Impact of the renovation scenarios on the overall CO_2 emissions

Also providing photovoltaic modules, roof insulation or a well performing boiler to all Belgian dwellings hardly reduces the CO_2 emissions to the level of 1990, even less to a level 20% below the reference of 1990. Only by combining different scenarios, the goal of 20% CO_2 reduction or max. 20 Mtons CO_2 emissions can be achieved in 2020: the combination of energy performance scenario PRES 1 combined with a renovation grade of 75% results in 19,6 Mtons, whereas PRES 2 combined with a renovation grade of 50% results in 18,8 Mtons.

5. Confrontation and discussion

The results from the scenario analysis of CO_2 reduction in the building stock clearly show that large efforts are needed to achieve the goal of 20% reduction: 50% of all buildings renovated by 2020 according to a PRES2 energy performance regulation, being all new buildings are passive houses and the renovated buildings also really low energy houses. However, as the EL²EP-project showed, the financial impact of PRES 2 for the building owner is enormously, due to the extra investment cost of more than 200€/m² floor area. If a PRES1 energy performance regulation is adopted, being the economic optimum, the extra investment cost is around 120€/m², but in this case 75% of all buildings should be renovated by 2020. And although the payback time for the economic optimum is less than 10 years, investing this initial extra cost is not feasible for the majority of the Belgian population without extra financial support. Furthermore, it is highly questionable that the building contractors are able to renovate 50% to 75% of all dwellings (ca. 2 – 3 Million) within the next 12 years.

6. Conclusions

The EL²EP-project deduced an economic optimal combination of energy saving measures and evaluated the position of passive and zero energy houses to this optimum. The project on the scenarios for CO_2 emission reduction on the other hand analysed what measures are needed to achieve a CO_2 reduction in the building stock of 20% by 2020 compared to 1990. From these two projects, it can be concluded that there is a substantial financial barrier for a more sustainable building stock, apart from other barriers. A more constant policy of financial support is indispensable in order to take away part of this barrier.

7. Acknowledgements

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