Cost benefit analysis of Passive Houses and Low-Energy Houses compared to Standard Houses

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Abstract— As the energy demand used for space heating accounts for 78% of EU15 household delivered energy consumption significant reductions in energy demand can be achieved by promoting low energy buildings.

Energy efficiency in buildings has become a key goal of any energy policy. Europe relies on the Energy Performance of Buildings Directive (EPBD), which has been converted by Flanders into the 'Energy Performance and Interior Climate' (EPB). Taking into account this Flemish EPB-standard (in terms of maximum U-values, E-level and K-value), Our study investigates three building types: the standard house, the low-energy house and the passive house. As more far-reaching measures concerning energy savings usually lead to higher investments, the aim of our study is to perform an economic analysis in order to determine the economic viability of the three building types [1].

Keywords—cash flow, cost benefit analysis, low-energy house, passive house, payback time

I. Introduction

The actual debate on global warming cranks up the search for environment-friendly alternatives to maintain our current living standards and level of activity. The issue is increasingly being addressed on a global level, a condition sine qua non to achieve results. The main step is the Kyoto Protocol, as amendment on the International Treaty on Climate Change, which aims at reducing the emission of greenhouse gases (GHG) by 5% under the 1990-level by 2012.

The European debate has been concentrated on the contribution by different stakeholders in the environmental issue. As Figure 1 illustrates, the public electricity and heat production accounts for 30% of greenhouse gas emissions [2]. Logically, most reductions can be realized in this sector. Different technologies have been and still are under investigation and development, such as solar, wind, biomass or tidal energy. These green energy sources should permit to reduce greenhouse gas emission while safeguarding energy production and thus our current living standard and level of activity.

As can be seen in Figure 1 and according to Schnieders and Hermelink [3] houses provide an important possibility to build on our way towards sustainable living standards, especially concerning energy. This fourth significant source of GHG emissions concerns the residential and commercial (including institutional) sector, which accounts for 17% of all emissions [2]. The large and merely untapped savings potential currently gains more attention, both in the research world and amongst the general public.

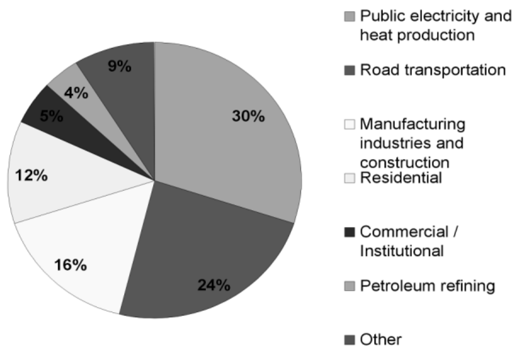

Figure 1: Sources of greenhouse gas emissions in CO2 equivalent (Tg) in the EU-15 (2005) [2]

Governments elaborate support mechanisms to stimulate energy-efficiency in existing and new buildings. The potential GHG emission reduction in the housing sector will be addressed in this paper from an economic point of view.

As the energy demand used for space heating accounts for 78% of EU15 household delivered energy consumption [4], significant reductions in energy demand can be achieved by promoting low energy buildings [5]. This currently largely untapped potential offers significant opportunities to reach the Kyoto objectives [6].

In their article, Schnieders and Hermelink [3] suggest that passive houses offer a viable option to meet the remaining energy demand only with renewable sources, within the boundaries of availability of renewable energy and affordability. However, our analysis questions the economic viability of passive houses. Therefore, an economic analysis will be carried out, in order to compare the potential of standard houses, low-energy houses and passive houses from an economic investment point of view.

II. MAIN CONCEPTS

The Belgian government has laid the responsibility for energetic policies of buildings with the different regions (Flanders, the Walloon region and Brussels). Only in the Flemish region, legislation is currently operational through the EPB legislation (Dutch abbreviation for Energy Performance Interior Climate). These rules apply to all construction works (whether new development or renovation) for which urban development permits are required. The EPB legislation only concerns buildings with cooling and / or heating systems, aiming at creating a specific interior climate for people. As different requirements apply to new development and renovation, only the former will be discussed within the framework of this article.

A. Calculation of the K-value

The K-value of a building is a number to evaluate the amount of heat loss trough the area of heat loss, taking into considering the degree of insulation as well as the compactness of the building.

$\frac{V}{A}$[m] = t he compactness of a building is the quotient of the sheltered volume (V) trough the area of heat loss (A).

λ [W/mK] = the heattransmission-coefficient

- Insulation materials : $\lambda \leq 0{,}065$ W/m.K
- Materials with an insulating behavior : $0{,}065 \leq \lambda \leq 0{,}15$ W/m.K
- Non-insulation materials : $\lambda \geq 0{,}15$ W/m.K

Singular material	**Multiple materials**
R[m²K/W] = heat resistance $= \frac{d}{\lambda}$ with d = the thickness of the material	R[m²K/W] = heat resistance $= \sum_i R_i$ with R_i = the heat resistance of the singular materials
U[W/m²K] = heat transmission coefficient $= \frac{1}{R}$	k[W/m²K] = heat transmission coefficient $= \frac{1}{R}$

The k-value and the U-value reflect the amount heat loss there is every second through 1m² area of a certain material. In se there is no difference between the definitions of the k-value and the U-value. In practice they are confused. In the following formula only the term k-value is used for all heat transmission coefficients.

k_s[W/m²K] = global heat transmission coefficient for a building

$$= \frac{\sum_i c_i k_i A_i}{\sum_i A_i}$$

with $c_i = 1$, external wall or floor in direct contact with the sub ground

$c_i = 2/3$, floor of wall adjacent to a not heated room

$c_i = 1/3$, floor of wall adjacent to a not heated room

Formula to calculate the K-value of a building

$\frac{V}{A} \leq 1m$	$K = 100k_s$
$1m \leq \frac{V}{A} \leq 4m$	$K = \frac{300k_s}{\frac{V}{A}+2}$
$4m \leq \frac{V}{A}$	$K = 50k_s$

B. Calculation of the E-level

The characteristic annual primarily energy consumption is the primarily energy consumption for a house during one year in the assumption that the interior temperature is constantly 18°C including forfeiter internal gains of heat.

This definition is very strict making use of primarily energy, for houses these are oil and gas. Secondary energy such as electricity has to be translated in terms of primarily energy. The factor of multiplication to convert this second type of energy is 2.5 in Belgium, which means a reduction of energetic return of 40% due to production and transportation losses. Many other countries are more conventional assuming a reduction of 33%, corresponding to a factor of 3.

The calculation of the characteristic annual primarily only includes the energy consumed to heat locations [X1], prepare warm water, helping functions of installations and ventilation systems, cooling. All this energy demanding consumptions are reduced with energy produced by photovoltaic panels or cogeneration. This means that single electrical equipments are not taken into account; only fixed installations are incorporated in the calculations. The mean advantage of this is the creation of an objective bases for comparisons. On the other hand only a fictive energy consumption level is used in the calculations and not the real consumption, which can differ a lot depending of the inhabitants of the residence.

The E-level of a building is a comparison between the annual primarily energy consumption of the building with a predefined reference. This value of reference is determined by means of a number of house specific parameters. These parameters make it possible to compare different house with each other in terms of energy consumption. A big house will have larger energy consumption than a smaller house, but this doesn't implicate that the large house less energy-efficient than the smaller house.

The three incorporated parameters are: the shape, the size and the conscious ventilation flow. The area of heat loss determines the shape of the building. This area of heat loss is defined, as the external area through witch there can be loss of heat. The sheltered volume expresses the size of the building. The conscious ventilation flow is determined in the design of the residence. After calculating these three factors for the residence the E-level can be determined:

$$E = 100 * \frac{\text{charactheristic anual primary usage}}{a_1 * A + a_2 * V + a_3 * F}$$

With a_1=115; a_2=70 and a_3=105
A= the area of heat loss
V= the sheltered volume
F= the conscious ventilation flow

a_1, a_2 and a_3 are constants determined by the Flemish Government. To qualify these constants a set of referential package of measures is developed and applied to 200 geometrical different houses. The values of the three constants are the values giving rise to a mean E-level of 100 for these 200 buildings. If a building has an E-level less then 100 means that it is more energy efficient than the referential package of measures. When the E-level exceeds the value of 100, additional measures should be taken to make the house more efficient with energy.

Both legislations, the old one dating from 1991 and the new EPB, are compared in Table 1:

Table 1
Comparison of two energy saving legislations

Legislation 18/09/1991	**EPB legislation**
K55	K45
	$E \leq 100$ Controlled ventilation flow $\geq 30m^3/h$ per person

In order to facilitate controls and preceding calculations, EPB software has been developed, which enables architects and controlling authorities to compute the E-value and the corresponding energy need, according to the specific characteristics of a building.

As stated in the previously, the residential and commercial sector offers substantial potential in the struggle to reduce GHG emissions. Often, three types of buildings are currently under investigation: the standard building, the low-energy building and the passive house. These main concepts are delineated according to the definitions presented by Satori and Hestnes [7] and Badescu and Sicre [8]:

- Conventional building or standard building: Refers to a building built according to the common practice of a specific country in a specific period, meeting the minimal legally required energetic standards. \item
- Low-energy building: Refers to a building built according to special design criteria aimed at minimising the building's operating energy.
- Passive house: A type of low-energy building; design is oriented to make maximum exploitation of passive technologies (eventually adopting also some active solar technology), assuring a comfortable indoor climate during summer and winter without needing any conventional heating or cooling system.

These definitions serve as guidelines throughout the article. To make things more tangible, the Belgian (Flemish) requirements will be used, as for each of the three building types the EPB legislation has concretized the definitions with specific values for some key elements as shown in Table 2. These values will be used throughout this paper for all computations.

Table 2
Key values under EPB legislation

Type	**Building requirements**
Standard building	▪ $\leq$ K45 ▪ $E \leq 100$ ▪ Controlled ventilation flow $\geq 30m^3/h$ per person
Low-energy building	▪ K30 – K45 ▪ Yearly energy need for heating purposes ≤ 30 kWh/m² ▪ Controlled ventilation flow $\geq 30m^3/h$ per person
Passive House	▪ K15 – K20 ▪ Yearly energy need for heating purposes ≤ 15 kWh/m² ▪ Primary energy need ≤ 120 kWh/m² ▪ Controlled ventilation flow $\geq 30m^3/h$ per person

III. SAMPELS

The starting point of the quantitative analysis is the passive house. This house is redesigned into five different types of passive houses, three low-energy buildings [9] and three standard houses. The geometry of the house is kept identical; only the building materials differ from one type to another. Concerning the building method, distinction will be made between houses built through the traditional methods and wooden buildings (WB). Additionally the insulating material differs with the house types, as illustrated in Table 3[10-11].

Table 3
Studied houses

Type	Building Method	Lagging material
Standard	Traditional WB + crepy WB + parament	pur4 WB9+rockwool9+isomo4 WB9+rockwool9
Low-Energy	Traditional WB + crepy WB + parament	pur8 WB14+rockwool14+isomo8 WB14+rockwool14+pur5
Passive	Traditional Traditional WB + crepy WB + parament WB + parament	isomo26 kooltherm2x9 WB14+rockwool14+isomo20 WB14+rockwool14+isomo20 WB14+rockwool14+cooltherm12

IV. SPECIFIC ADDITIONAL COSTS

The specific extra costs related to passive houses compared to low-energy houses and standard houses can be broken up into 7 categories, e.g. costs for heating, ventilation, insulation, airtightness, ground works, differentiation in net floor surface and miscellaneous costs. There is a difference in net surface of the building because of the thicker walls in a passive house and the low-energy house. Under miscellaneous costs we take into account a small difference due to the applied building method. A traditional building method is a little cheaper than wood build. Nevertheless this difference is negligible. The prices of all building materials have been obtained with an architect who designed these 11 houses.

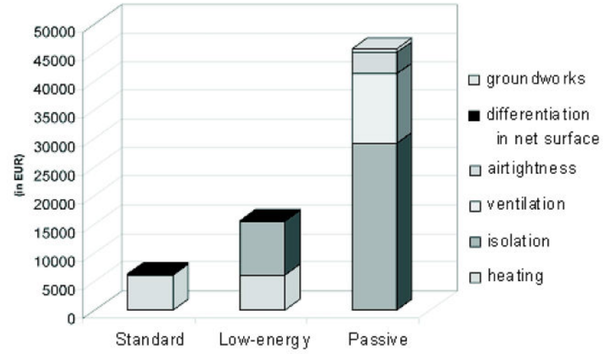

Figure 2: Analysis of the specific additional costs of three building types.

Figure 2 is a graphical reflection of the different extra costs divided into these 7 categories. The additional costs for insulation and ventilation result in the biggest surplus cost for the passive house of respectively 64% and 27% of total costs.

V. ENERGIE COSTS

The calculation of the energy cost for the different houses is based on their determination of the energy need. This energy need is calculated through the EPB-software for every house. As in Belgium gas is the primary energy source for heating the energy cost is calculated by use of a mean gas price of 0.04euro/kWh.

As the cost benefit analysis is performed over the lifetime of a house, a growth rate has to be introduced in the cost calculations to correspond with reality. Therefore different scenarios will be investigated with different growth rates between 0% and 25%.

VI. SUBSIDIES

In Belgium one can receive subsidies to build energy-saving houses at different governmental levels: national, provincial and municipal. The amount of subsidies depends on the use of high efficiency glass for the windows and the insulation level of the roof. In the simulations only the national subsidies are taken into account, because of the big variation in the other subsidies. The calculations actually lead to a subsidy of 721.06euro for the standard house and the maximum subsidy of 2600euro for the low-energy and the passive house.

VII. OVERVIEW OF THE COST

Table 5 gives an overview of the most relevant figures for the performed analyses.

Table 5
Most relevant figures used in the cost benefit analysis

	Total cost (€)	Subsidies (€)	Energy cost(€)
Standard	244191	721	1849
Low-energy	253459	2600	1248
Passive	283401	2600	600

All the analyses will be performed at constant energy costs. Therefore no discount rate is taken into account. This is a partial compensation for not considering inflation. In the analyses with growing energy costs, these will be discounted by the return of government bonds with duration of 20 years. Their interest rate is taken at the actual rate of 4.49%. The calculations are done making use of nominal growing rates and interest rates, eliminating the influence of inflation.

VIII. BREAK-EVEN ANALYSIS

All the analyses have a term of 20 years and will take into account the specific surplus cost during the building of the house, the possible subsidies and potential energy savings.

A. Constant energy costs

The graph showing the time needed to recover the net costs with constant energy prices starts at the net additional cost en adds every year the corresponding energy costs as shown in figure 3.

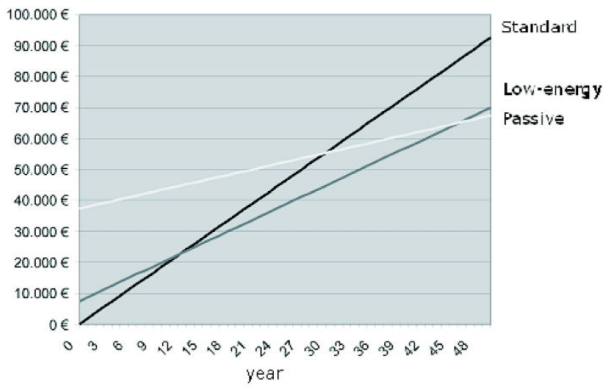

Figure 3: Break-even time (constant energy costs).

The break-even time for the low-energy house compared to the standard house is 12.3 years and 29.9 years for the passive house. The extra costs of the passive house are not in proportion to the savings in energy costs in comparison with the low-energy house. Only after 47 years the passive house is more rentable than the low-energy house.

B. Growing energy costs

Figure 4 shows the evolution of the costs if the energy cost annually grows with 10%. For this case the time needed to recover the more cost of a passive house is 18 years in comparison to a standard house and for the low-energy house the recovery time is 9.5 years. When we compare the passive house to the low-energy house the break-even time is 24 years.

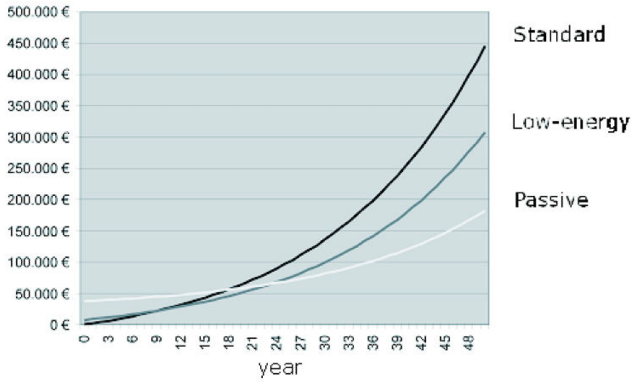

Figure 4: Break-even time (growing energy costs).

A sensitivity study investigating the influence of growing energy costs on break-even times shows a big influence of this energy growth rate. The results of the sensitivity analysis are presented in Table 4. Three comparisons are made: standard to
low-energy house, standard to passive house and low-energy to passive house. The break-even time shown in the table is the year the total costs of the second house type are lower than the first.

Table 6
Sensibility study to the growth of the energy cost

Annual growth of the energy costs (%)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Low-energy to standard	17	15	14	13	12	12	11
Passive to standard	>100	55	40	33	28	25	23
Passive to low-energy	>100	>100	77	53	42	36	31
Annual growth of the energy costs (%)	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Low-energy to standard	11	11	10	9	9	9	9
Passive to standard	22	20	18	18	16	16	15
Passive to low-energy	28	26	24	22	21	20	19
Annual growth of the energy costs (%)	**15**	**16**	**17**	**18**	**19**	**20**	**25**
Low-energy to standard	8	8	8	8	8	7	7
Passive to standard	14	14	13	13	12	12	10
Passive to low-energy	18	17	16	16	15	15	12

Especially for the passive house the break-even time decreases significantly when energy growth rates increase. Nevertheless the break-even time stays more than 20 years compared to the low-energy house, unless the growth rate exceeds 14%. Even with a growth rate of 25%, passive houses only start paying off after 12 years compared to low-energy houses.

IX. CASH FLOW ANALYSIS

The elaborated case study assumes a mortgage of 20 years. The mortgage finances the total cost needed for the building of the house. As it is impossible to know the evolution of a variable mortgage for the coming 20 years the current fixed interest rate of 5.48% is chosen to perform the simulation.

A. Constant energy costs

In this section another three comparisons are elaborated: standard to low-energy house, standard to passive house and low-energy to passive house. Table 7 shows the monthly difference in the family budget for the three types of houses.

Table7
Difference in the monthly and yearly costs

	Difference in mortgage payment	**Difference in energy costs**	**Total monthly difference**	**Total yearly difference**
Low-energy to standard	50.2€	-50.07€	0.13€	1.51€
Passive to standard	253.58€	-104.06€	149.52€	1794.26€
Passive to low-energy	203.38€	-53.98€	149.40€	1792.75€

Because of the financial spread of energy savings over 20 years, the initial extra costs are also spread over this term. Therefore the initial additional cost can partially be returned by the saving in energy expenditures during 20 years. The results are clearly in favor of the low-energy house. This house type has an additional annual cost of 1.51euro. After 20 years the family lives in a house with a annual energy cost of 600euro, which is much lower than the energy costs of the other 2 types (see Table 2 The passive house implies an annual extra cost of 1794.26euro. This means a monthly difference of 149.52euro, a less negligible amount compared to the monthly more cost of a low-energy house.

B. Growing energy costs

To consider the influence of growing energy costs, three scenarios are simulated namely an annual growth rate of 5% (Table 8), 10% (Table 10) and 15% (Table 11).
The values given in the resulting tables are the cash flow of the first house minus the cash flow of the second house. A positive difference means the second house has a lower outlay than the first house and vice versa.

Table 8
Cash flow analysis with a growth percentage of 5%

years	**1**	**3**	**5**
low-energy to standard	1.51	-55.03	-107.37
passive to standard	1794.26	1526.14	1279.43
passive tot low-energy	1792.75	1581.18	1386.80
years	**6**	**8**	**10**
low-energy to standard	-132.07	-178.77	-222.10
passive to standard	1163.52	945.56	744.75
passive tot low-energy	1295.60	1124.33	966.85
years	**11**	**13**	**15**
low-energy to standard	-242.60	-281.43	-317.57
passive to standard	650.32	472.55	308.83
passive tot low-energy	892.92	753.98	626.10
years	**16**	**18**	**20**
low-energy to standard	-334.70	-367.24	-397.64
passive to standard	231.31	85.74	-48.81
passive tot low-energy	566.01	452.99	348.83

Table 8 shows the cash flow with a growing percentage of 5%. The low-energy house has already a positive impact on the family budget after 2 years. The passive house however needs 20 years before the cash flow is positive compared to the cash flow of the standard house. When the cash flow of the passive house is compared to that of the low-energy house even after 20 years there is not a positive impact.

It should be noticed that the figures in the table shows the impact on the annual family budget. The passive house having a positive impact on the budget after 20 years does not mean becoming profitable. It only means that from that time on the passive house starts to cost less in terms of family budget than the standard house. The cumulative additional costs over a 20 years timeframe have to be recovered before the passive house becomes profitable. This break-even time is shown in table 9.

Table 9
Profits based on the cash flow analysis

	5%	
	Year of profit	**Total profit after 20 years (€)**
low-energy to standard	2	4396.86
passive to standard	>20	-15229.13
passive tot low-energy	>20	-19625.99
	10%	
low-energy to standard	2	12257.74
passive to standard	20	1106.35
passive tot low-energy	>20	-11.151.39
	15%	
low-energy to standard	2	26450.26
passive to standard	14	30599.43
passive tot low-energy	19	4149.17

Table 10 shows a similar analysis with an annual growing rate of the energy costs of 10%. Again, the low-energy house has a positive impact on the family budget after 2 years. The passive house has a positive impact on the annual family budget after 11 years. Comparing the passive house with the low-energy house, the impact is positive after 15 years.

Table 10
Cash flow analysis with a growth percentage of 10%

years	1	3	5
low-energy to standard	1.51	-114.20	-232.68
passive to standard	1794.26	1403.20	1019.02
passive tot low-energy	1792.75	1517.39	1251.7
years	**6**	**8**	**10**
low-energy to standard	-293.31	-418.08	-548.54
passive to standard	828.46	448.25	66.40
passive tot low-energy	1121.77	866.33	614.94
years	**11**	**13**	**15**
low-energy to standard	-616.29	-757.68	-908.10
passive to standard	-126.23	-517.14	-918.63
passive tot low-energy	490.06	240.54	-10.54
years	**16**	**18**	**20**
low-energy to standard	-987.15	-1153.96	-1333.79
passive to standard	-1124.53	-1549.12	-1994.20
passive tot low-energy	-137.38	-395.16	-660.41

The more the energy prices increase the more the impact of the passive house becomes positive. Therefore a third scenario is implemented with a growth rate of 15% of the energy costs. The results are shown in table 11. These 3 tables show that the time the passive house needs to have a positive impact on the family budget becomes smaller when the growth percentage of the energy costs increases. In the last scenario the passive house only needs 8 years to have a positive impact on the budget. The low-energy house has again a positive influence on the family budget after 2 years. In order to conclude these analyses, an answer is provided to the question which timeframe has to be considered in order to determine the break-even time of the low-energy house and the passive house. This implies a positive value for the cumulative yearly impacts on the family budget. The results of this analysis are shown in Table 11.

Table 11
Cash flow analysis with a growth percentage of 15%

years	1	3	5
low-energy to standard	1.51	-176.11	-376.29
passive to standard	1794.26	1274.53	720.58
passive tot low-energy	1792.75	1450.64	1096.87
years	**6**	**8**	**10**
low-energy to standard	-486.69	-732.37	-1017.95
passive to standard	426.61	-204.87	-909.08
passive tot low-energy	913.30	527.51	108.87
years	**11**	**13**	**15**
low-energy to standard	-1178.58	-1542.28	-1973.19
passive to standard	-1294.71	-2147.60	-3131.97
passive tot low-energy	-116.13	-605.32	-1158.78
years	**16**	**18**	**20**
low-energy to standard	-2218.42	-2779.21	-3450.75
passive to standard	-3683.19	--4926.50	-6393.39
passive tot low-energy	-1464.77	-2147.29	-2942.65

Comparison of the low-energy house with the passive house demonstrates the profitability of the low-energy house after 2 years. The passive house is only profitable in the cases the growth of the energy costs is higher than 10% and is only more profitable than the low-energy house if the growth is more than 15%. The low-energy house is profitable in all the cases compared with the standard house. In the case of an increasing energy cost with 15%, the gain can rise to 26450 euro after 20 years.

X. CONCLUSION

The analysis is based on 11 different houses, divided into three categories: the standard house (3), the low-energy house (3) and the passive house (5). In the first step the specific additional costs of every type is studied and compared with the others. From this study, it can be concluded that the extra cost of the low-energy house is 4% and of the passive house is 16% in comparison with the standard house. Insulation and ventilation are the main causes for this surplus cost.

By means of the E-level of the buildings the corresponding need of energy is determined. Based on the current gas price, the energy costs are calculated for the different types of houses.

Based on all these costs a break-even time is calculated comparing the three types of houses. This analysis shows this break-even time is always shorter for the low-energy house than for the passive house. Nevertheless it is very dependent on the growth of the energy prices, but when we impose a maximum time of regain for the passive house, the annual growth of the energy prices would be minimally 25%. For an annual growth of 9%, the return time is 20 years.

The cash flow analysis calculates the impact of the choice of housing type on the annual family budget. The results show that the low-energy house is the safest choice with a minimal impact on the family budget considering constant energy prices. The passive house has the first 20 years a negative influence on the budget of 1794euro in this scenario. After 20 years both energy saving houses (passive and low-energy) have a positive impact on annual the family budget, because of the omitted mortgage and the remaining measures for energy saving. In the scenarios with increasing energy prices the low-energy house has a positive impact on the budget after 2 years for every case. The positive impact of the passive house reach up to 26450euro after 20 years in the case the energy costs increase annually with 15%.

The impact of the passive house is strongly dependent on the evolution of the energy prices. In the case the energy prices increase with 5%, the impact on the family budget is significantly negative (15229euro) over a 20 years timeframe. In the case the energy prices increase with 10% the passive house becomes just rentable after 20 years with a total gain of 1106euro. In the case of an annual growth of 15% the passive house becomes very profitable. After 20 years the family has a total gain of 30599 euros.

As energy price growth rate is unpredictable, a low-energy house is the safest choice at this moment, because its profit is less dependent on future energy prices. In most of the realistic cases considered this house is more profitable than the passive house and even when energy prices increase significantly, the difference between the gains of the passive house and those of the low-energy house remain rather small.

The best investment for the individual builder therefore currently is the low-energy building. Therefore, when energy saving buildings are to be promoted at large scale, governments should aid with larger subsidies to make passive houses more attractive to individuals planning projects in the residential sector.

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