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HOW DEEP TO GO: REMARKS ON HOW TO FIND THE COST-OPTIMAL LEVEL FOR BUILDING RENOVATION

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All views expressed in this report are those of the author and not necessarily those of eceee.

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1 Background

Currently the energy performance requirements in some member states are far from cost-optimal levels [EC 2008]. The European Commission's proposal for the recasting of the EPBD [EC 2008] and the respective European Parliament's amendments [EP 2009] aim at gradually moving from current levels to *cost-optimal* levels for the overall energy performance of new *and existing* buildings. Among others the Parliament's amended proposal says [EP 2009]:

(Article 1) "This Directive lays down requirements as regards:

> …
>
> (c) the application of minimum requirements on the energy performance *of existing buildings* that are subject to major renovation *and of the building components and technical building systems* whenever they are replaced or retrofitted;"

(Article 2) "For the purpose of this Directive, the following definitions shall apply:

> …
>
> (3) "energy performance of a building" means the calculated or measured amount of energy needed to meet the *primary energy demand* associated with a typical use of the building, expressed in *kWh/m2 per year*, …"
>
> (10) "cost-optimal level" means the level where the cost-benefit analysis calculated over the *life-cycle of a building* is positive, taking into account at least the *net present value* of investment and operating costs (including energy costs), maintenance, earnings from energy produced and disposal costs, where applicable."

(Article 4)

> "3. As from 30 June 2012 Member States shall *only* provide *incentives for* the construction or major renovation of *buildings* or parts thereof, including building components, the results of *which comply at least with minimum energy performance requirements* achieving the results of the calculation referred to in Article 5(2).

(Article 5)

> 2. Member States shall calculate cost-optimal levels of minimum energy performance requirements using the common methodology …

(Annex IIIa)[1] "In setting a common methodology for calculating cost-optimal levels, the Commission shall take into consideration at least the following principles:

- define *reference buildings* that are characterised by and representative of their functionality and geographic location, including indoor and outdoor climate conditions. The reference buildings shall cover residential and non-residential buildings, both new and existing;.
- define *technical packages …of energy efficiency* and energy supply measures to be assessed;
- assess the corresponding *energy-related* investment costs, energy costs and other running costs of the technical packages applied to the reference buildings from the *societal perspective as well as from the perspective of the property owner or investor;*

eceee welcomes the emphasis on existing buildings and life-cycle costing approaches. However in the meantime many Member States expressed their preference for putting an emphasis on new buildings, while others judge the proposed recast as "overly ambitious" [CEU 2009]. This might delay or avoid the full exploitation of the major savings potential that can be found in the stock of existing buildings.

Following a discussion with eceee, Ecofys was assigned to compose a short paper with key facts on cost-optimal levels of renovations. The study is mainly based on publications of German-speaking authors and on German prices. It is self-evident that construction prices and energy prices in other European countries might differ – nevertheless the basic calculation principles discussed in this paper are unaffected by these differences.

The key issues – with a strong focus on the first one – addressed in this paper are:

1. Calculation of cost-optimal levels in renovation
2. Examples based on real-life experience
3. Inclusion of societal costs and sustainable levels of renovation

[1] Compared to the original European Commission's proposal [EC 2008] for the recast of the EPBD, in [EP 2009] the European Parliament has introduced Annex IIIa entirely new, whereas the excerpts from Articles 1, 2, 4 and 5 cited before have only been modified.

2 Selected Key Issues

2.1 Calculation of cost-optimal levels in renovation

2.1.1 Overview

Current calculations for cost-optimal levels of renovation often suffer from major distortions. Distortions can happen in both directions: either making the investment look better or worse.

Distortions that often make investments look	
better	worse
static calculations	application of payback method
exponential energy price increase	high interest rates
	zero residual values
	too short life-times
	questionable alternatives

Table 1: Distortions in investment calculations

Before going into the details, it is noteworthy that in this chapter we are only dealing with the investment perspective of a property owner or private investor. This means, although certainly having a positive monetary value, the following co-benefits of energy efficiency measures that are correctly implemented are not considered (cf. [PHI 2008]):

- Higher independency from energy imports
- Mitigation of externalities like global warming (external costs)
- Higher quality energy services resulting in better health like,
    - Better thermal comfort
    - Better indoor air quality.
- Risk reduction
    - Less risk of damaging the building construction
    - Less poverty risk in case of steeply increasing energy prices.

At the same time the paper does not discuss the “investor-user dilemma” as this is not about the efficiency of an energy saving investment but mainly on how to fairly distribute its benefits.

In the following problems resulting from static calculations, exponential energy price increase and payback calculations will be shortly highlighted.

The other distortions mentioned in Table 1 still remain even when applying life-cycle costing and net present values. This will be illustrated by using the example of adding exterior wall insulation, where the initial calculation is improved step-by-step, by removing one distortion after another.

Assumptions [PHI 2008]

- German price level for installations
- Lifetime of exterior insulation: 40 years
- Price of 5 cm insulation (thermo skin): € 90/m^2, additional insulation €1/cm and m^2.
- U-value of original wall: 1.41 W/m^{2}K.
- Lambda of exterior insulation: 0.04 W/mK.
- Average real energy price incl. saved auxiliary energy: of 6.8 ct/kWh.
- Heating degree hours: 78 kKh
- Average efficiency of heating system: 90%.

2.1.2 Distortion 1: Static calculations

Static calculations do not take into account interest rates.[2] In real life, regardless if an investment in better energy performance of buildings is financed from private equity or mortgage loans either the investor or the bank will require a return on investment.

Example

Assuming an additional investment for energy efficiency of € 1,000 with a lifetime of 10 years and resulting annual savings of € 100 a static calculation will result in a profit of € 0. Obviously there is no money left for paying any interest. In reality this will result in a loss.

Solution

An interest rate > 0 % has to be accounted for. The recast proposal suggests the calculation of net present values, which means discounting future cash flows to the time of investment by applying an interest rate > 0%. In principle this distortion is eliminated in the recast proposal.

2.1.3 Distortion 2: Exponential energy price increases

Inferring from historic price developments to future price assumptions is often done by applying inconspicuously small annual price increases. Problems of this approach especially occur when it is about long-term investments like in better energy performance of buildings.

Example

The following chart illustrates the effect of annual *real* price increases of 1%, 2%, 5% and 10% for a lifetime of 40 years, which would be typical for an exterior wall insulation.

[2] Apart from that major aspect, static calculations also exclude real-life characteristcs such as changes in energy prices, investment costs or legal requirements.

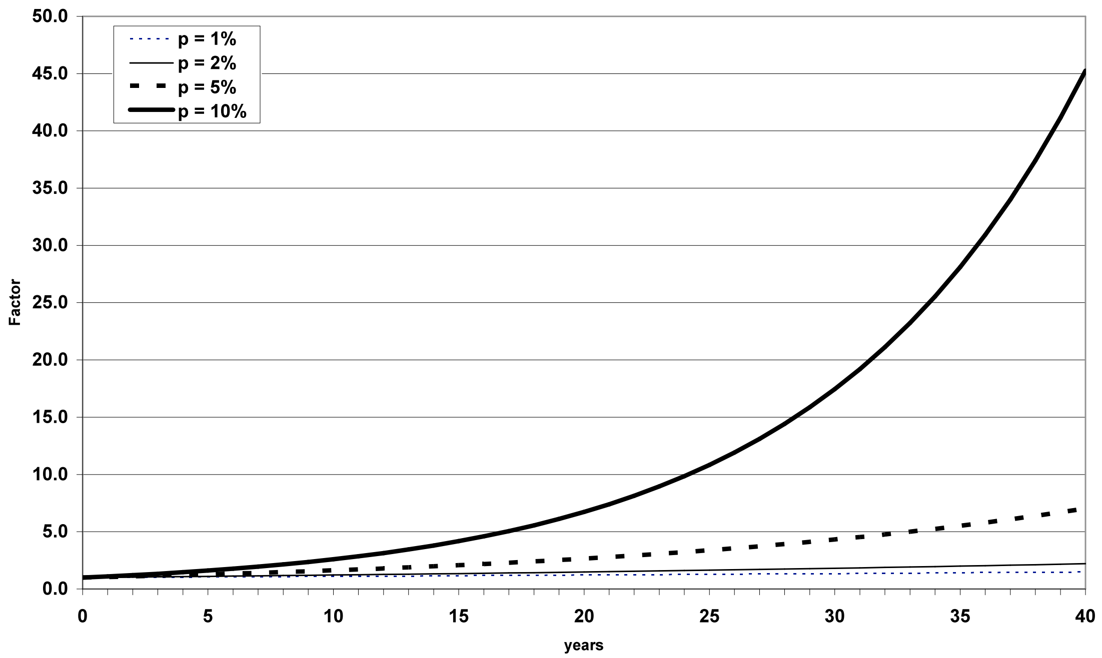

Figure 2: Exponential price increases

The results after 40 years are a 49%, 121%, 604% or 4,426% *increase* in real prices. Assuming a current level of €60 for one barrel crude oil and taking 5% this would mean a *real* price of more than € 400 by the end of the period. With this, energy efficiency investments would result in enormous savings that most probably will never occur as long as the energy markets work.

Solutions

It seems to be realistic to assume substitution processes for fuels from a certain price level on. For example, liquefaction of coal can be done for considerably less than € 100/barrel. Therefore it is more serious to assume an average price level for the period under consideration. In [PHI 2008] this approach is followed taking 6.6 ct/kWh consumer *real* price for gas/oil.

This can be elaborated to an approach where the costs and benefits of energy efficiency investments are not mixed up but kept separate and expressed in a way which makes them easily comparable for an investor, based upon his personal judgement on future energy prices. This is achieved by calculating the "***investment per saved kWh of final energy***": This works as follows:

- The initial investment is re-calculated into equal annuities for the lifetime of the energy efficiency measure investment. This is done by multiplying the investment with the appropriate annuity factor which is based upon realistic lifetimes and interest rates.

Annuity factors						
		Lifetime (years)				
		5	10	15	20	50
real interst rate	3.00%	0.218	0.117	0.084	0.067	0.039
	3.50%	0.221	0.120	0.087	0.070	0.043
	4.00%	0.225	0.123	0.090	0.074	0.047
	4.50%	0.228	0.126	0.093	0.077	0.051

Table 2: Annuity factors

- Finally the annuity is divided by the annual energy saving. Now the "*investment per saved kWh of final energy"* can be compared with the current or any assumed future energy price in order to decide about the profitability of the energy investment.

2.1.4 Distortion 3: Payback method

The payback time is calculated by dividing the initial investments by the monetary value of predicted annual energy savings. However, the alternative with the shortest payback may not be the one that yields the highest profit. Above in many cases the so-called "static payback time" is calculated, i.e. without taking interest rates into account; in this case the same drawbacks as mentioned in chapter 2.1.2 apply.

Example

An investor wants to decide between two alternatives.

- Alternative 1, having a lifetime of 5 years, needs an investment of € 800, the estimated annual savings are € 200. The static payback time is 4 years.
- Alternative 2, having a lifetime of 10 years, needs an investment of € 1,500, the estimated annual savings are € 300. The static payback time is 5 years.
- Based on static payback, Alternative 1 is the better option. However, talking about long lasting goods like buildings, Alternative 2 is the one that yields the higher profit: After 10 years the (static) net benefit of Alternative 1, which we assume to be replaced by the same kind after 5 years, is € 400. Alternative 2 yields a significantly higher profit of € 1,500.

Solution

Payback calculations tend to prefer cheaper investments that not only tend to result in smaller savings but also to have shorter lifetimes. Especially talking about buildings having lifetimes of several decades the payback calculation is an inappropriate tool to prepare decisions that are to pave the way towards a sustainable development. What is needed instead is a calculation method that gives an indication about the net benefit of a long-term investment. The recast proposal suggests the calculation of net present values, which means discounting future cash flows to the time of investment and adding them up to the investor's net benefit. Thus in principle this distortion is eliminated in the recast proposal.

2.1.5 Distortion 4: High interest rate

Investments in better energy performance of buildings are usually financed by mortgage loans. For the purpose of this study we take 5.0% for a 20 years mortgage. For a start, this is also taken as the calculation period for the annuity of the investment. Nevertheless it can be observed that sometimes interest rates are taken, which are significantly higher than for mortgage loans and only might be achieved with investing private equity in higher risk projects.

Example

The optimal insulation thickness i.e. the insulation thickness where the lowest *"cost per saved kWh final energy"* is reached is calculated with an interest rate of 8%. Taking the assumptions mentioned in 2.1.1:

- The minimum *cost per saved kWh final energy is 10.1 ct/kWh.* This is more expensive than buying energy.
- The insulation thickness at this point is 16 cm
- The energy saving at this point is 85%.
- The annual profit per m^2 insulation (calculated from annual energy savings minus annual capital cost) at this point is -3.43 € i.e. a loss. (See also Table 4, below.)

Solution

The calculation has to be done at the mortgage interest rate. Above, inflation has to be eliminated in order to get the *real* mortgage interest rate as the comparative energy price of 0.068 €/kWh also has been calculated as a real price.

Taking a mortgage rate of 5.0% and an inflation rate of 1.7% the *real* mortgage rate is 3.24% (PHI 2008). The result changes as follows:

- Now the minimum *cost per saved kWh final energy is 6.82 ct/kWh.* This is the same price as for buying energy.
- The insulation thickness at this point is 16 cm
- The energy saving at this point is 85%.
- The annual profit per m^2 insulation (calculated from annual energy savings minus annual capital cost) at this point is -0.02 €.

2.1.6 Distortion 5: Questionable alternatives

The best time for a major renovation or for improvements of components is when a renovation has to be done anyway. The cost for these non-energy "anyway investments" has to be subtracted from the energy efficiency investments as they are not their cause. In many cases energy efficiency investments are coupled with "anyway investments", nevertheless in many cases the whole investment is balanced against the energy savings. In fact this is a major mistake in many calculations as it implicitly means, that "doing nothing", i.e. keeping the current state of e.g. walls, windows, roofs, heating system etc. would be a real option for another couple of decades.

Example

As an extension to the previous step it is taken into account that the plaster would have had to be replaced anyway at a cost of € 40/m^2.

- Now the minimum *cost per saved kWh final energy is 4.10 ct/kWh.* This is significantly cheaper than buying energy.
- The insulation thickness at this point is 12 cm
- The energy saving at this point is 81%.
- The annual profit per m2 insulation (calculated from annual energy savings minus annual capital cost) at this point is 2.66 €.

Solution

As the example shows, a realistic alternative action for the energy efficiency improvement is not "do nothing" but renewal of the plaster which leads to a much smaller share of investment that can be allocated to the energy efficiency improvement.

2.1.7 Distortion 6: Zero residual values or too short lifetimes

As already stated the lifetime of the insulation is 40 years. Nevertheless in all previous examples the *total* cost has been allocated to the assumed calculation period of 20 years.[3] In fact it is not correct to allocate the *whole* investment cost for a long-lasting measure to a calculation period which is much shorter than the measure's lifetime. Apparently this leads to a bias when only the share of savings from the measure which lies within the calculation period is considered. Until here this distortion has been kept intentionally, in order to be able to show the effect of eliminating it.

Solution

It is financially correct to only allocate the share of the energy efficiency investment that delivers savings within the calculation period – in our case the first 20 years. This can be done by adding the net present values of the first 20 annuities and only taking this value into account. Consequently the residual is not taken into account. Table 3 shows the relative share of the residual in the total energy efficiency investment.

Residual values						
		Lifetime (years)				
		20	30	40	50	80
real interst rate	3.00%	0%	24%	36%	42%	51%
	3.50%	0%	23%	33%	39%	47%
	4.00%	0%	21%	31%	37%	43%
	4.50%	0%	20%	29%	34%	40%

Table 3: Residual values for a calculation period of 20 years

Example

[3] The decision about the length of the calculation period is up to the investor; as 20 years is a wide spread number, it has been taken here. Longer lifetimes increase the probability, that some components' lifetimes (e.g. boilers) may be shorter than the calculation period. This does not create a problem, it only means that the cost of the re-investment(s) has to be allocated to the remainder of the calculation period equivalent to the way described in this chapter.

As an extension to the previous step the residual value is not taken into account any more.

- The residual (3.24% real interest rate) is 35%, i.e. only 65% of the investment can be allocated to the calculation period of 20 years.
- Now, the minimum *cost per saved kWh final energy is 2.69 ct/kWh.* This is significantly cheaper than buying energy.
- The insulation thickness at this point is 12 cm
- The energy saving at this point is 81%.
- The annual profit per m2 insulation (calculated from annual energy savings minus annual capital cost) at this point is 4.07 €.

2.1.8 Decision support through visualization of cost-optimal levels

Without visualization it is not obvious if we are talking about a wide or small range of profitable solutions.

Solution

Visualizing the cost curve for the case described in chapter 2.1.7 helps to decide about the cost-optimal level of renovation.

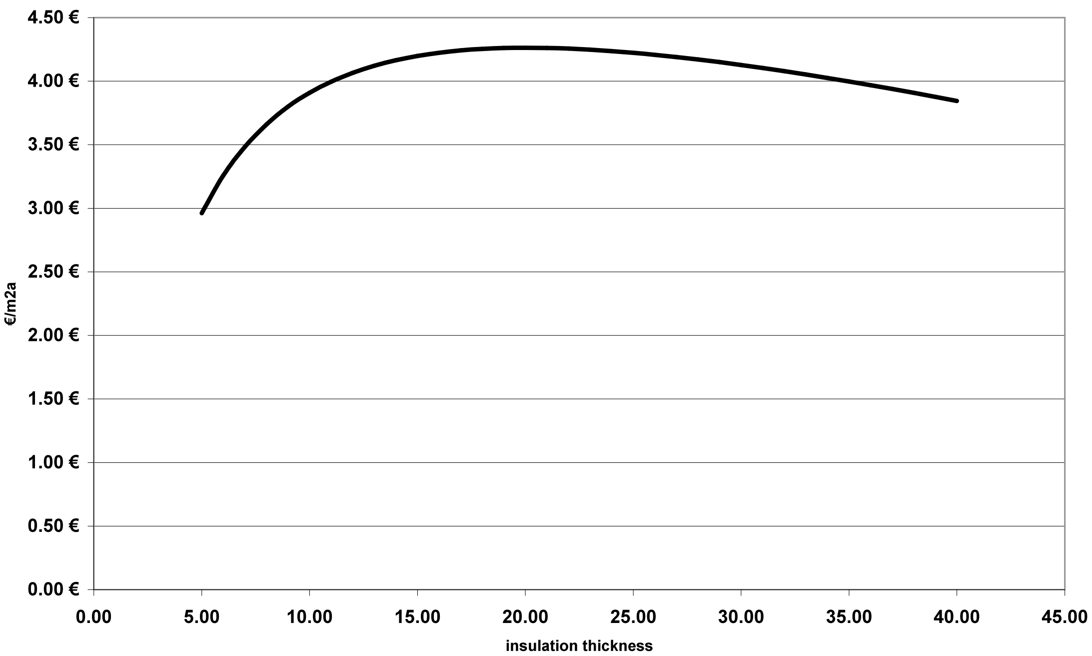

Figure 3: Cost optimal insulation thickness

Figure 3 shows two interesting pieces of information:

- The maximum profit is achieved at even higher insulation thickness – appr. 20 cm – than the minimum cost per saved kWh final energy.
    - At this point the cost per saved kWh final energy is 2.8 ct/kWh.

    - This is significantly cheaper than buying energy and leads to the maximum annual profit of € 4.26/m2 insulation
- There is a wide range of insulation thicknesses – 11 cm thru 35 cm where the annual profit varies only slightly between € 4.00/m2 insulation and € 4.26/m2 insulation.

Of course there is a considerable difference in energy savings achieved at 11 cm, 20 cm and 35 cm – 79%, 88% and 93%. If no other reasons contradict, in this case the pre-cautionary principle would make it advisable to choose an insulation thickness between 20 and 35 cm.

2.1.9 Summary

The previous stepwise approach demonstrated a wide difference in results for "cost-optimal levels" depending on the calculation methodology. For illustration purposes the case of additional exterior wall insulation was chosen. To avoid misunderstandings, the paper does not advocate a specific energy efficiency measure. The focus of this paper is on the calculation methodology and its effect on the results. The methodology can be applied to all kinds of energy efficiency measures, e.g windows, air-tightness, boilers, heat-recovery, renewable energy, feedback, insulation of roofs, walls etc. In real life calculations, usually several of the above mentioned distortions are implicitly or explicitly included. Eliminating one distortion after another gradually reveals the enormous economic saving potential that can be achieved by renovating the stock of existing buildings.

Elimination of distortions in calculating cost-optimal level

	Base case High interest	mortgage real interest	anyway investment	residual value	visualization
cost per saved kWh	10.1 ct	6.82 ct	4.1 ct	2.69 ct	2.8 ct
insulation thickness	16	16	12	12	20<s<35
energy saving	85%	85%	81%	81%	88%-93%
annual profit per m2	-3.43 €	-0.02 €	2.66 €	4.07 €	4.00-4.26 €

Table 4: Effect of eliminating distortions on cost-optimal levels

2.2 Examples based on real-life experience

2.2.1 Cost per saved kWh for various renovation measures

Following the approach pointed out in the previous chapter, [PHI 2008] demonstrates the cost per saved kWh for several renovation measures.

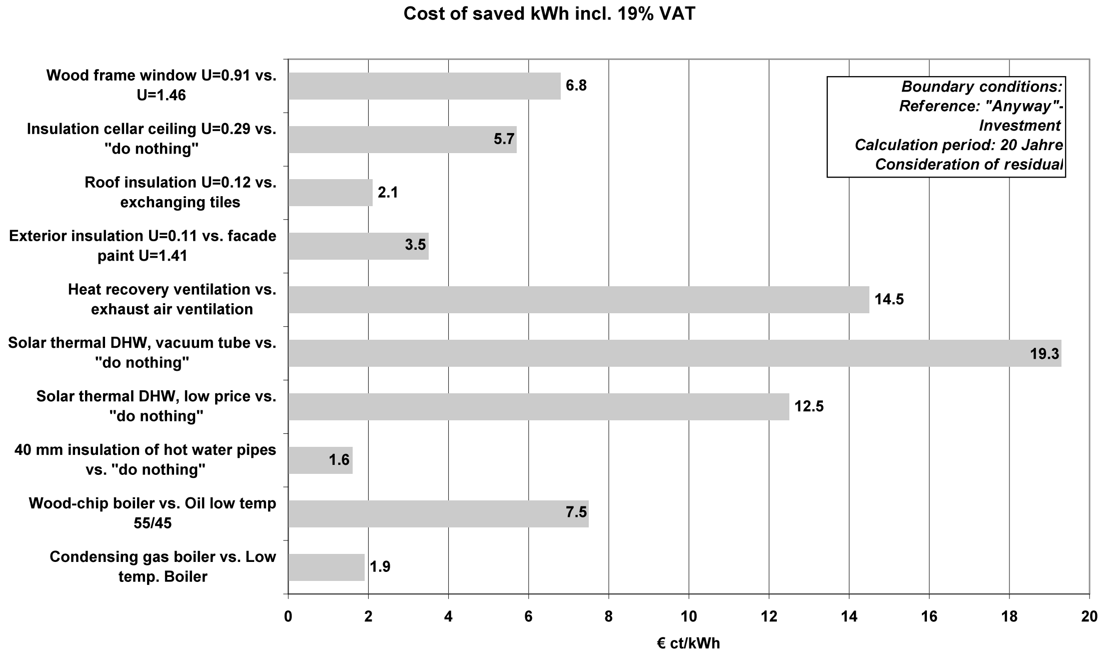

Figure 4: Cost per saved kWh for different renovation measures

2.2.2 Cost per saved kWh for a major renovation

While the previous examples show the cost for single measures, [Schulze-Darup 2003] has presented extensive results from cost efficient "Factor 10" renovations of whole buildings. In these renovations as far as possible passive house components have been applied.

The minimal standard for a major renovation is the level of the German energy saving ordinance for new buildings + 40% (primary energy). This is the reference alternative. Three more ambitious alternatives have been analyzed:

- A) Achieving new build standard
- B) Achieving 25% better than new build standard in terms of primary energy for space heating and DHW
- C) Achieving 58% better than new build standard in terms of primary energy for space heating and DHW ("3-litre-house")

For a multi-family building with 6 apartments and 895 m2 living area built in 1929 in Nurnberg the additional investment cost were calculated to be

- A) 124.53 €/m2 floor area
- B) 196.95 €/m2 floor area
- C) 255.05 €/m2 floor area

The same logic as in 2.1.7 is applied. As a major renovation combines several components that have different lifetimes, [Schulze-Darup 2003] suggests for simplification purposes an average lifetime for the whole renovation of 30 years. For precautionary reasons here we assume only 25 years which makes the results look worse. The results for the cost per saved kWh energy are as follows:

- A) 5.2 ct – achieved primary energy saving compared to non-renovation: 58%
- B) 7.1 ct – achieved primary energy saving compared to non-renovation: 68%%
- C) 7.6 ct - – achieved primary energy saving compared to non-renovation: 82%

B) and C) are more expensive than the assumed energy price of 6.8 ct/kWh. This is a case where in Germany subsidies step in which compensate for the additional cost.

2.3 Inclusion of societal perspective

Building a very low energy house instead of a "conventional" building can be interpreted like "building an energy saving plant", i.e. an energy saving measure on the demand side of the market like we know from Demand-Side-management (DSM) projects. In spite of in depth work on this topic during the 1990s, there is hardly any systematic transfer of those findings to energy efficiency matters beyond electricity utilities. This is especially the case for methods that have been developed for economic cost-benefit analysis. [Hermelink 2009] shows that these methods may be adapted in order to conduct a systematic *life-cyle comparison* between the two demand-side options "average renovation" and "renovation to a sustainable level". Although [Hermelink 2009] presents this approach for a real world new building it also may be applied to major renovations of buildings.

For this purpose it is useful to transfer the logic of two well established tests, representing the two perspectives of private investors and the society. *In fact this is exactly what Annex IIIa of the amended recast proposal requires (cf. chapter 1).*

- *Participant Test*. In this context the Participant Test answers the question of costs and benefits for the final customer, when he prefers a high efficiency building to a standard efficiency building.
- *Societal Test.* In this context this test is about the costs and benefits from society's perspective when a decision is taken in favour of a high efficiency building. This explicitly includes the consideration of external costs caused by this technology. Thus a major requirement of the Rio-declaration may be satisfied.

The societal test opens the possibility to integrate some of the "co-benefits" that have been mentioned in chapter 2.1.1. Again the mathematical base is the net present value as can be seen in Table 5.

Benefits	Cost
Avoided fuel cost (VBK)	Increase of fuel costs (EBK)
Avoided capacity costs (VKK)	Increased capacity cost (EKK)
Avoided costs for maintenance/repair (VWI)	Additional investment cost (SA)
Other (monetized) benefits incl. avoided transaction costs of the user (SMN)	Additional cost for maintenance/repair (WI)
Avoided external cost (VExK)	Other (monetized) additional benefits incl. additional transaction costs of the user (SMK)
$NPV_0 = \sum_{t=1}^{N} \left[\left(VBK_t + VKK_t + VWI_t + SMN_t + VExK_t \right) - \left(EBK_t + EKK_t + SA_t + WI_t + SMK_t \right) \right] \cdot \left(1 + p_s \right)^{-t}$	

Table 5: Costs and benefits used in the societal test

Applied to a comparison of passive house vs. low-energy house, both the participant test and the societal test result in the passive house being the more profitable option [Hermelink 2009].

3 Conclusions

A major driver for doubts about the economics of renovation or about their cost-optimal levels is the well-established practice of including several systematic distortions in cost-benefit calculations, that systematically increase the calculated cost per saved kWh. Eventually, although not necessarily intentionally, this practice cultivates sub-optimal, insufficient renovation levels or completely hampers renovations respectively. Eliminating these distortions step-by-step leads to a surprisingly high decrease in the resulting costs per saved kWh for one and the same energy efficiency measure. As the example in this paper illustrates, the identified distortions may easily add up to a "factor 3" between the "debugged" and "non-debugged" calculation results for the cost per saved energy. It is most important, that the "high-end" of the results' bandwidth may lead to costs per saved energy which are significantly higher than realistic assumptions about future energy prices while the "debugged" low-end result may lead to costs per saved energy which are significantly lower than realistic assumptions about future energy prices.

The train of thought presented in this paper confirms, that the current proposal for the recast of the EPBD and especially the amendments proposed by the European Parliament – life-cycle costing based on net present values – provide a sound basis for a subsequent development of a common methodology for calculating cost-optimal levels of renovation. The elaboration of such a common methodology would be most welcome as guidance for the discussion on economics of renovation. Such a methodology should identify all kinds of distortions, show their effect and eliminate them. An example how this could be done has been outlined in this paper. An approach like this would give a significant push to widespread renovation to very-low energy levels that may be considered *sustainable*.

But what is a sustainable level? Surprisingly few analyses of what can be considered to be sustainable levels of renovation from an energy perspective or, in other words, what is green *enough*, has been published up till now. For new buildings a systematic study of Zimmermann [2005] leads to a primary energy level of appr. 140 kWh/m^{2}a for space heat, DHW, household electricity and embodied energy, a level which is very close to the primary energy requirement for passive houses. Building on Zimmermann's study, from an energy life-cycle perspective [Hermelink 2006] analyses which renovation level should be achieved in order to be better than a rebuild option, where the old building is torn down and replaced by a new passive house. He concludes that "taking sustainability seriously, a space heat consumption between 25 and 40 kWh/m^{2}a should be aimed at" in renovation. Compared to the energetic level of the building stock this is equivalent with savings between 80% and 90%. A major pre-condition to achieve such levels is to replace commonly used inaccurate methods for the calculation of cost-optimal levels of renovation by more accurate ones.

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