Cost optimality – brake or accelerator on the way towards nearly zero energy buildings

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Keywords

cost efficiency, building codes, policy evaluation, Energy Performance of Buildings Directive (EPBD), cost optimality calculation

Abstract

Art. 5 of the recast Energy Performance of Buildings Directive (EPBD, Directive 2010/31/EU) requires EU Member States to take into account cost optimality when defining energy performance requirements by considering initial investment costs, running costs and replacement costs over the life-cycle of a building. In March 2012 the European Commission published the Delegated Act No. 244/2012 (including explanatory guidelines), in which the methodological approach of cost optimality calculations as to be applied under the EPBD is described. Although this regulation includes harmonised standards for some important input parameters, it leaves considerable degree of freedom to the Member States for selecting input parameters according to their choice. As a result, calculations on cost optimality will play a crucial role in setting the energy performance levels in the Member States and may act as brakes or accelerators on the way towards nearly zero energy buildings.

Based on long-term experience in life-cycle cost assessment of buildings and on selected examples of available cost optimality calculations from the Member States under the EPBD regime, the paper analyses – in a first step – the impact of the most important input parameters on the results.

In a second step an approach of a quick "top-down" plausibility check of cost optimality calculations is developed. This approach aims at increasing transparency of cost optimality calculations and follows several assessment steps "from general to particular", as follows:

- Check 1: Plausibility of the shape of the cost curve (e.g. flatness respectively steepness in certain energy performance areas);
- Check 2: Plausibility of the most important input parameters and their relation among each other;
- Check 3: Completeness of the methodology applied.

The paper concludes that a large share of cost optimality assessments which are available – including those presented in this paper – suggest that considerable tightening of minimum energy performance requirements can be argued not only from an energy performance but also from an economic point of view. On the other hand, since the EU regulation offers a high degree of freedom on the actual implementation of cost optimality calculations, very different results cannot be completely excluded.

Introduction: Cost optimality as guiding principle in the EPBD

The revised version of the EU Directive 2002/91/EC (namely, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010) on the energy performance of buildings (EPBD) requires that the cost efficiency over the life-cycle of buildings is taken into account when requirements for the energy performance of buildings are established. National minimum standards should be set by the Member States based on the cost optimum for construction costs and operational costs for both new buildings and major renovations.

Furthermore the European Commission has submitted the regulation No. 244/2012 (hereinafter called EU regulation) in accordance with the objective clause of the EPBD in March

2012. Within the scope of this EU regulation, the methodological approach for the analysis of cost optimality for requirement levels is determined bindingly.

The cost optimality principle acts as a bridge between the standard energy performance – as it is usual on today's markets – and the intended goal of reaching nearly-Zero-Energy-Buildings (nZEB) by 2020 (at least for new constructions). In this sense the period between now and 2020 can be interpreted as a "transition period" during which the markets are forced to adapt and to apply a life-cycle cost perspective instead of the usual construction cost perspective.

It has to be stressed, however, that the cost optimality principle as defined in the EPBD offers a high degree of freedom when it comes to its application in the building regulations. Although the EU regulation on cost optimality provides uniform regulations in some respects – e.g. concerning included cost elements, calculation algorithms and analysis period – it allows room for national stipulations in many key areas, such as:

- definition of the reference building related to important assumption such as size, form, compactness, share of window areas etc.;
- selection of variants (packages of measures) which are assessed;
- construction costs (and most important construction cost differences for different qualities);
- maintenance costs of relevant building elements and related price developments;
- the assumed (technical resp. economical) life-time of building elements;
- discount rates;
- starting level of energy prices;
- energy price trends (although the regulation includes a recommendation to use the "official EU forecast member states are allowed to use other forecasts for their assessments).

Input parameters and assumptions driving the results of cost optimality calculations

Taking into account the flexibility of the regulatory framework described above, the question remains if the application of the cost optimality principle in national building regulations will really push forward the building performance levels towards nZEB or if it will turn out as a brake for this necessary development since member states will get arguments that actual minimum requirements are already – more or less – at cost optimal levels. Starting from this question, the following sections present two examples of cost optimality calculations. Furthermore an assessment of important influencing factors is derived and a "plausibility check" for the validity of cost optimality calculations is developed.

EXAMPLE A: COST OPTIMALITY CALCULATION FOR A SINGLE FAMILY HOUSE IN AUSTRIA

This example shows a cost optimality calculation for a single family house (SFH) in Austria [Leutgöb et al., 2012] . A reference building has been defined, using data from another research project which had explored reliable and market-based construction cost data [Haus der Zukunft, 2012]. The defined SFH consists of two storeys with dimensions of 13 × 8.5 m each. Thus, the building has a gross floor area of 221 m². The surface-volume-ratio is typical for a residential building of this size, featuring a value of 0.68. Moreover, the reference building has a window area ratio of 16 %, which was kept constant in the variant analysis. The reference building is designed as a solid building (brick) with upgraded insulation. The same type of construction has been used in all variant investigations.

Description of technical variants assessed

Table 1 shows the selection of technical variants which have been calculated.

With respect to the quality of the building envelope 5 different variants have been analysed. They correspond to the Austrian standard and are defined according to the level of achieved net heating demand lines (NHD-lines 16, 14, 12, 10 and 8[1]. In order to derive the different envelope qualities which are expressed by NHD-lines, the single building elements (window, wall, ground floor, ceiling etc.) were improved step by step. For example, a net heating demand line of 8 represents the *envelope* quality of a passive house which also includes technical measures for minimising thermal bridges.

Two different forms of heating supply systems – namely pellets (home central heating) and heat pump (brine-water heat pump, surface collector) – were examined. It is assumed that these two heating supply systems are typical of SFH in rural and suburban areas, i.e. for these areas where SFH are prevailingly built.

Additionally, variants were calculated, for which very high thermal insulation standards (NHD-lines 10 or 8) were combined with a heat recovery ventilation system. In these cases net heat demand lines of 4.4 and 6.4 arise. These variants represent the ideal-typical passive house approach, where the heating is provided exclusively via the ventilation system and no static heating system is installed.

Finally, renewable energy systems are taken into account, since they play a crucial role regarding the path towards nearly zero energy buildings. Article 2 of the EPBD specifies that the low energy needs of low-energy buildings have to be covered to a large extent by energy from renewable sources, which is preferably produced on-site or nearby. Therefore, appropriate variants have to be considered in the analysis of cost optimality, too. For the present cost analysis of the SFH models with thermal solar energy and other variants with photovoltaics are investigated.

Description of main input parameters and assumptions

Besides defining the reference buildings and assessed variants, the cost optimality calculation requires a long list of input data, which have been determined as follows:

1. In order to derive the net heating demand the compactness needs to be introduced. The respective Austrian building regulation defines the net heating demand as follows: NHD = NHD-Line ´ (1+3/lc) where lc is the reciprocal value of the surface-volume-ratio of the building. Therefore, for the given building with an lc value of 1.47 the corresponding NHD for NHD-line 16 would be 48.6 kWh/m2a and for NHD-line 8 it would be 24.3 kWh/m2a.

Table 1. Overview of analysed technical variants (packages of measures).

No.	quality of envelope (net heating demand line)	ventilation system	heating supply system	RES-solar
1	NHD-line 16	no	pellets	no
2	NHD-line 14	no	pellets	no
3	NHD-line 12	no	pellets	no
4	NHD-line 10	no	pellets	no
5	NHD-line 8	no	pellets	no
6	NHD-line 16	ventilation	pellets	no
7	NHD-line 14	ventilation	pellets	no
8	NHD-line 12	ventilation	pellets	no
9	NHD-line 10	ventilation	pellets	no
10	NHD-line 8	ventilation	pellets	no
11	NHD-line 16	no	heat pump	no
12	NHD-line 14	no	heat pump	no
13	NHD-line 12	no	heat pump	no
14	NHD-line 10	no	heat pump	no
15	NHD-line 8	no	heat pump	no
16	NHD-line 16	ventilation	heat pump	no
17	NHD-line 14	ventilation	heat pump	no
18	NHD-line 12	ventilation	heat pump	no
19	NHD-line 10	ventilation	heat pump	no
20	NHD-line 8	ventilation	heat pump	no
21	NHD-line 6,4	ventilation as heating system	heat pump	no
22	NHD-line 4,4	ventilation as heating system	heat pump	no
23	NHD-line 14	no	pellets	solar-thermal
24	NHD-line 10	no	pellets	solar-thermal
25	NHD-line 14	no	heat pump	PV
26	NHD-line 10	no	heat pump	PV

- Construction cost data are usually different to gain, since there exist considerable cost differences on the market, depending on the region, point in time, quality of material etc. In order to prevent mixing different information sources, cost data for the different measures have been gained from a review of concrete offers for the given reference building, i.e. these cost data are based on market information.
- Life-times for building elements have been differentiated: 60 years for insulation materials, 35 years for windows, 20 years for the heat supply (boiler house, solar collectors) and for the central ventilation station; 35 years for the heating and the ventilation distribution;
- The assumptions for maintenance costs were taken from the market reviews;
- Energy prices were assumed with a starting level of €0.05/kWh for pellets and €0.1655/kWh for electricity (special tariff for heat pumps). An annual price increase of 4 % in real terms was assumed.
- Since the calculation reflects the private investor's perspective VAT was included on the construction cost side as well as on the running cost side. Subsidies were not taken into account because there exist several different schemes in Austria.
- The discount rate was fixed at a level of 2 % in real terms which – although rather low – is in line with actual interest rate levels for longer-term mortgage loans.

Short presentation of results

Based on the assumptions described above, a life cycle cost analysis has been performed, which includes construction costs, maintenance costs, possible renewal costs for individual building elements and energy costs. Figures 1 and 2 provide an overview of the main results of the calculation for the baseline scenario of the SFH reference building.

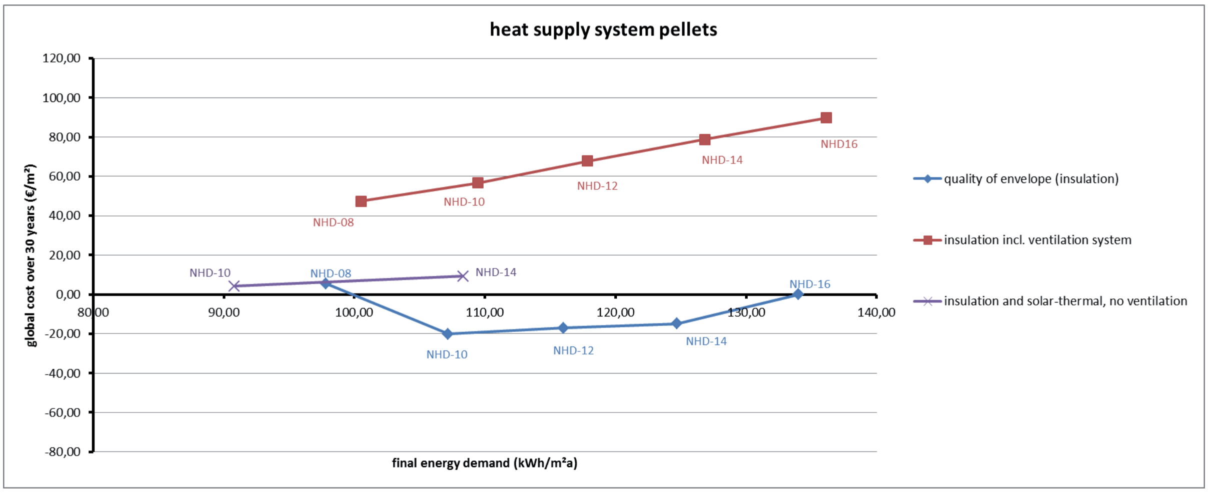

Figure 1. Cost curves for the reference SFH with heat supply based on pellets – cost difference compared to the actual level in the building regulation.

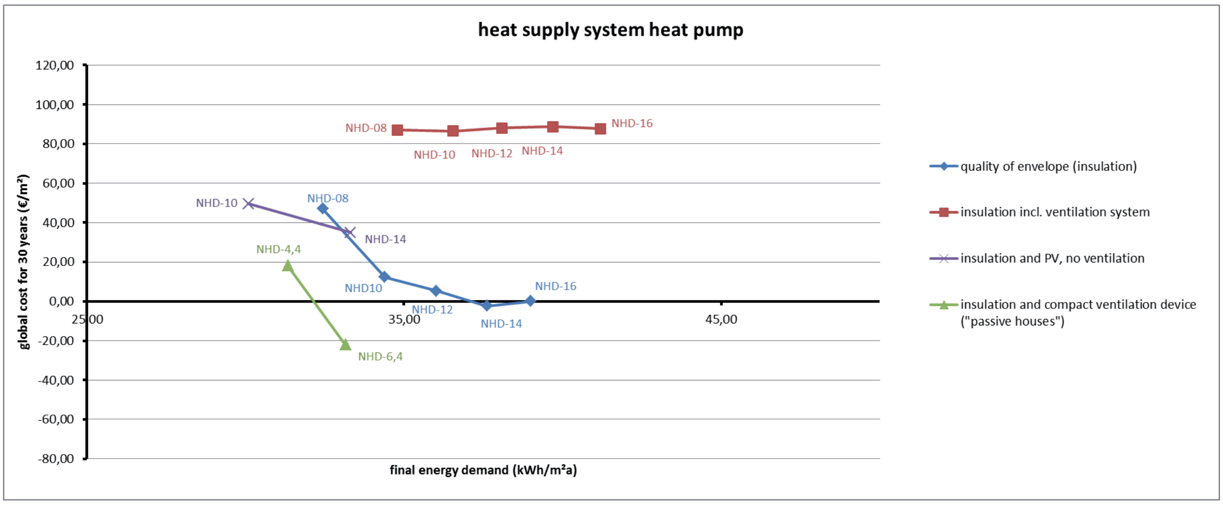

Figure 2. Cost curves for the reference SFH with heat supply based on heat pump – cost difference compared to the actual level in the building regulation.

The main results can be summarized as follows:

- The SFH with pellets-based heating system basically shows a pattern where the progression of the cost curves for comparable variants is extremely shallow. The versions without ventilation systems are less expensive than the versions with ventilation system. However, the difference in costs between the two variants which achieve heat demand line 8 is not that high, meaning that ventilation systems tend to get competitive with very high standards of the envelope. The variants with solar panels – for the case of SFH – do not improve the economic performance of the building. However, the extra costs of these variants over the entire life cycle are quite low (although subsidies are not taken into account).
- Concerning the investigated variants with heat pump, the cost optimum is at net heating demand line 14 for variants in which only the envelope quality is varied (blue line in the figure), but the cost curve is still very flat in the area between net heating demand lines 10 to 16. Only when the net heating demand line of 8 is approached, a cost jump can be observed. Primarily, this is due to additional costs related to increased demands on the absence of thermal bridges, which is required for building physical requirements and for comfort reasons. It should be emphasized, however, that even in this case the differences in costs of around €50 per m² are limited over the observation period of 30 years (equivalent to around €0.14/m² and month).
- The "ideal-typical" passive house concepts, which feature a combination of high thermal standards of the building envelope with a ventilation system and a heat pump implemented as compact device prove to be very cost-effective as well.

Discussion of main driving factors

In order to check the robustness of the results presented above, a series of sensitivity analyses have been conducted:

- scenario of lower energy price increase: 2.8 % instead of 4 %;

Table 2. Summary description of the reference building.

Building geometry	**N° of floor =**	4
	A/V ratio =	0.47 m^{-1}
	Orientation:	S/N
	Area of S façade =	262 m^2
	Area of E façade =	128 m^2
	Area of N façade =	262 m^2
	Area of W façade =	128 m^2
	Shares of window area on the building envelope =	16%
	Floor area m^2 (as used in building code) =	924 m^2
Description of the building	**Construction materials:**	Hollow brick, concrete, air gap, plaster
	Typical air infiltration rate:	Ach = 2,5 h^{-1}
	Use pattern:	Typical
	Age:	Typical for years '60–'80
Description of the average building technology	**U value of wall =**	1.20 W/m^2K
	U value of roof =	1.40 W/m^2K
	U value of basement =	2.10 W/m^2K
	U value of windows =	3.50 W/m^2K
	g value of windows (in absence of solar shading)=	0.8
	Technical building systems:	Standard gas boiler, distribution pipes without insulation, radiators, low efficient chiller, mechanical ventilation
	Passive systems:	–

- scenario of a higher discount rate: 3 % instead of 2 %;
- reduction of a shorter life-time of insulation from 60 to 35 years.

The sensitivity analyses confirm the overall picture. There are no significant changes in relation to the cost optimality of the different variants which were investigated. Generally speaking, the results prove to be very stable as far as changes in energy price trend, life-times or the discount rate are concerned. Only in a few cases the cost optima move only slightly for the cost calculations of the SFH, in absolute terms the cost difference remain at a rather limited level.

Major influence on the results can prevailingly be expected from the following variations:

- If there is a concentrated bias into one direction for a bundle of input factors (first of all for discount rate, energy starting prices and future trends) – either in favour of or against energy efficiency – one may suspect that the cost curve would start to "incline". In this respect the "spread" between discount rate and future energy price development is of crucial importance – i.e. if the rates for these to input factors fall apart very much.
- The assumed cost data, however, are even more important. In this respect not the absolute cost but the cost differences related to different qualities of energy performance are decisive. Unfortunately the study presented above lacks a specific sensitivity analysis in this respect. The huge influence of additional cost related to the minimisation of thermal bridges for the very energy efficient variants (NHD-Line 8) gives, however, a strong indication of the importance of the assumption related to cost differences.

EXAMPLE B: COST OPTIMALITY CALCULATION FOR AN OFFICE BUILDING IN DIFFERENT CLIMATES

Description of main input parameters and assumptions

As reference for this example, a medium-size office building has been selected: a suburban building with 4 storeys and floor-to-ceiling height of 3 m (see Table 2[2]). For internal loads we considered a medium-low employment density with the schedules shown below and an average thermal gain of 8.75 W/m^2. The lighting power is assessed to be 10 W/m^2 in offices, 7 W/m^2 in the hallways and in the toilets. In our simulations the artificial lighting is dependent on the natural lighting and so on the solar protection use. The artificial lighting is supposed switch off during non-occupancy. As sizing parameter of office appliances, a specific power of 10 W/m^2 has been considered.

In estimating the energy needs for heating and cooling, 21 envelope variants were generated. Keeping the building geometries/orientations and the usage schedules fixed, in this paper we present an example where we chose to simulate the effect of three technological packages of increasing performance ("low", "medium", "high") in the three technology areas:

2. Infiltration rate (average over one year) calculated with the AirFlowNetwork of EnergyPlus, assuming that windows and external doors have an air tightness of class 1, according to the classification established in EN 12207.

Table 3. Envelope families considered in this analysis.

Area	Measure	Package 1 (low)	Package 2 (medium)	Package 3 (high)
"e"	Roof U-value [W/m²K]	1.5	0.3	0.1
	Wall U-value [W/m²K]	1	0.32	0.14
	Basement U-value [W/m²K]	2.1	0.32	0.2
"w"	Window U-value [W/m²K]	3	2	0.8
	Air infiltration rate: ach [h^{-1}]	0.8	0.5	0.1
"c"	Total solar transmittance (or g-value) (window + shading)	0.8	0.6	0.3
	Night natural ventilation rate: ach [h^{-1}]	0	0	2
	Envelope reflectance	0.3	0.3	0.5

Table 4. Combinations of envelope packages to generate variants analysed herein.; Legend: 1 means "Package 1 (low)"; 2 means "Package 2 (medium)"; 3 means "Package 3 (high)".

Area:	"e"	"w"	"c"
Variant 1 (base case)	1	1	1
Variant 2	1	1	2
Variant 3	1	1	3
Variant 4	1	2	1
Variant 5	1	2	2
Variant 6	1	2	3
Variant 7	2	1	1
Variant 8	2	1	2
Variant 9	2	1	3
Variant 10	2	2	1

Area:	"e"	"w"	"c"
Variant 11	2	2	2
Variant 12	2	2	3
Variant 13	2	3	1
Variant 14	2	3	2
Variant 15	2	3	3
Variant 16	3	2	1
Variant 17	3	2	2
Variant 18	3	2	3
Variant 19	3	3	1
Variant 20	3	3	2
Variant 21	3	3	3

i) opaque envelope ("e"); ii) windows (frame and glazing) ("w"); iii) passive cooling strategies ("c").

Starting from the energy demand and considering the following technology variations (appropriately coupled) more of 40,000 envelope-system variants were generated.

In addition to the RES systems indicated in Table 5 (heat pumps), we considered variants of photovoltaic (panels of monocrystalline silicon with a peak power factor of 0.15 kW/m²) and thermal solar systems (vacuum tubes with an efficiency of 72 %) integrated on the building roof. For each building variant the size of the solar fields (a combination of thermal and PV panels) was obtained by considering a useful available roof area (assumed to be 40 %).

The simulation has been carried out within the EnergyPlus dynamic simulation environment (version 7.0). For obtaining building envelopes fully comparable in terms of comfort performance, the energy needs for all the building variants are calculated assuming the same indoor conditions: i) the same operative temperature (21 °C in winter and 25 °C in summer) and relative humidity (35 % in winter and 65 % in summer) setpoint; ii) the same value (0.96 h^{-1}) of air change (coherent with the assumed occupation levels and the ventilation rates proposed by EN15251 for very low-polluted buildings).

For this analysis three perspectives have been considered: financial A, financial B and macro-economic. We show below the values considered for the main parameters of calculation.

Short presentation of results

We show below the results obtained for the reference building type in the reference climatic-economic context. In particular, the following findings can be drawn from the analysis:

A. Global costs versus (net) primary energy performance: under the specified set of hypothesis, this analysis may prove useful for identifying the "cost-optimal" and "nearly zero-energy" zones, in each climate and for each building typology. It may also be used to recognize the role of solar RES.

B. Sensitivity analysis on changes of the lower profile (Pareto Frontier) of the energy/cost domain as a function of several key economic perspectives: this analysis allows a quick perception of the trends, but – introducing imprecision due to a polynomial interpolation – it is not aimed at supporting a discussion about the position of the cost-optimal zone.

C. Disaggregation of building costs for several building variants positioned on the lower profile (Pareto Frontier[3]) of the energy/cost domain: it gives an impression of the relative weight of capital costs of energy related technologies, present value of costs incurred for energy over the 30 year time-horizon.

3. Pareto optimality is a concept that formalises the trade-off between a given set of mutually contradicting objectives. A solution is Pareto optimal when it is not possible to improve one objective without deteriorating at least one of the other.

Table 5. Variants of heating/cooling system elements considered in this analysis.

Plant	Sub-plant	Variant description	Performance factor			
			$\eta_{HEATING}$			$\eta_{COOLING}$
			η_{h1}	η_{h2}	η_{h3}	η_{c1}
Heating	Generation	Standard gas boiler	80%	80%	80%	
		Condensing boiler	104%	95%	–	
		Air source Heat pump with high SPF (and SEER)	350%	225%	–	300%
		Ground source heat pump	500%	325%	–	450%
	Emission	Standard radiant floor	98%	96%	94%	
		Insulated radiant floor	99%	98%	97%	
		Radiator	95%	94%	92%	
		Fan coil	96%	95%	94%	
		Air diffuser	96%	95%	94%	
	Distribution	Internal – not insulated	98%	96%	95%	
		Internal – a bit insulated	99%	97%	96%	
		Internal – insulated	99%	98%	97%	
	Control	Climatic	86%	84%	80%	
		indoor thermostatic	97%	95%	91%	
		climatic+indoor thermostatic	98%	97%	95%	
Cooling	Generation	Chiller with medium SEER				200%
		Chiller with high SEER				300%
		Air source Heat pump with high SEER (and SPF)	350%	225%	–	300%
		Ground source heat pump	500%	325%	–	450%
	Emission	Standard radiant floor				97%
		Insulated radiant floor				97%
		Insulated radiant ceiling				98%
		Fan coil				98%
		Air diffuser				97%
	Distribution	Internal – insulated				99%
	Control	Climatic				90%
		indoor thermostatic				98%
		climatic+indoor thermostatic				99%
Heat Recovery		Absent	0%			
		high efficiency	80%			

Discussion of main driving factors

The analysis has been conducted in four EU climates (Paris, Budapest, Stockholm and Catania) for buildings in an urban setting. Keeping hence in mind the crucial importance of the actual boundary conditions (building typology, orientation, shading by surrounding buildings, etc.) which might differ in the considered context, we draw here some indications on the main influencing variables:

- Overall there is an indication that mild climate and abundant solar irradiation make zero energy houses in southern climates of Europe technologically feasible with global costs over 30 years that equal or that are lower than those of ordinary buildings built today. Heating energy needs can be reduced to a minimum via the use of highly insulated envelopes, air tightness and heat recovery on ventilation. With relatively low internal loads the cooling energy needs can be also reduced to low values by using passive technologies (solar protections and controls, night ventilation, etc.). Cooling energy needs, however, would rise when internal loads and ventilation rates are relatively high (e.g. in our simulation exercise for offices: 10 W/m^2 lighting, 10 W/m^2 office equipment, ach = 0.95 h^{-1}).

Table 6. Main input data of Paris context.

	2010			**2020**		
Perspective	**Financial A**	**Financial B**	**Macro-economic**	**Financial A**	**Financial B**	**Macro-economic**
Real interest rate	4%	10%	2%	4%	10%	2%
Calculation period	30 years					
Primary/Delivered conversion factor for electricity	2.58			2.06		
Primary/Delivered conversion factor for natural gas	1					
Price of electricity (taxes excluded)	0.115 €/kWh_{el}			0.144 €/kWh_{el}		
Price of natural gas (taxes excluded)	0.053 €/kWh_{th}			0.066 €/kWh_{th}		
Price of electricity sold to the grid	0.048 €/kWh_{el}			0.059 €/kWh_{el}		
Real escalation rate of energy prices	2.5%					
Investment cost for new buildings not related to energy use (tax excluded)	1,000 €/m^2					
VAT	15%					
Taxes on electrical energy	24%					
Taxes on natural gas	20%					
Subsidies and incentives	Excluded					
Taxes	Included		excluded	included		excluded
Costs of avoided environmental damage (25 €/tCO_2)	Excluded		Included	excluded		Included

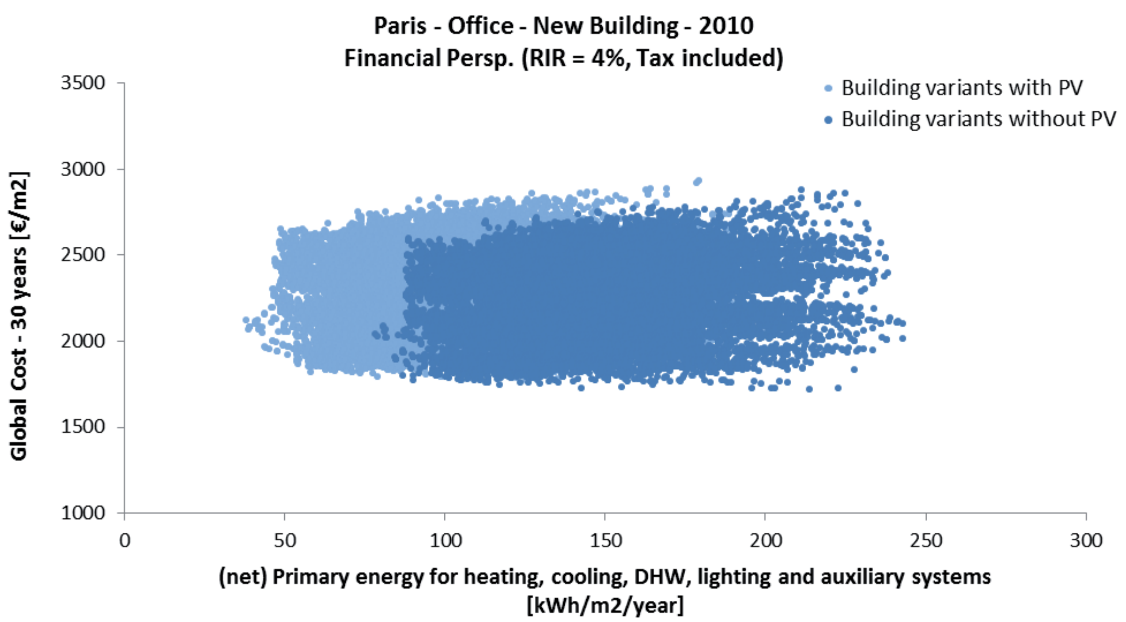

Figure 3. Global costs versus (net) primary energy performance calculated for new buildings in financial perspective (RIR = 4 %), considering the cost data 2010.

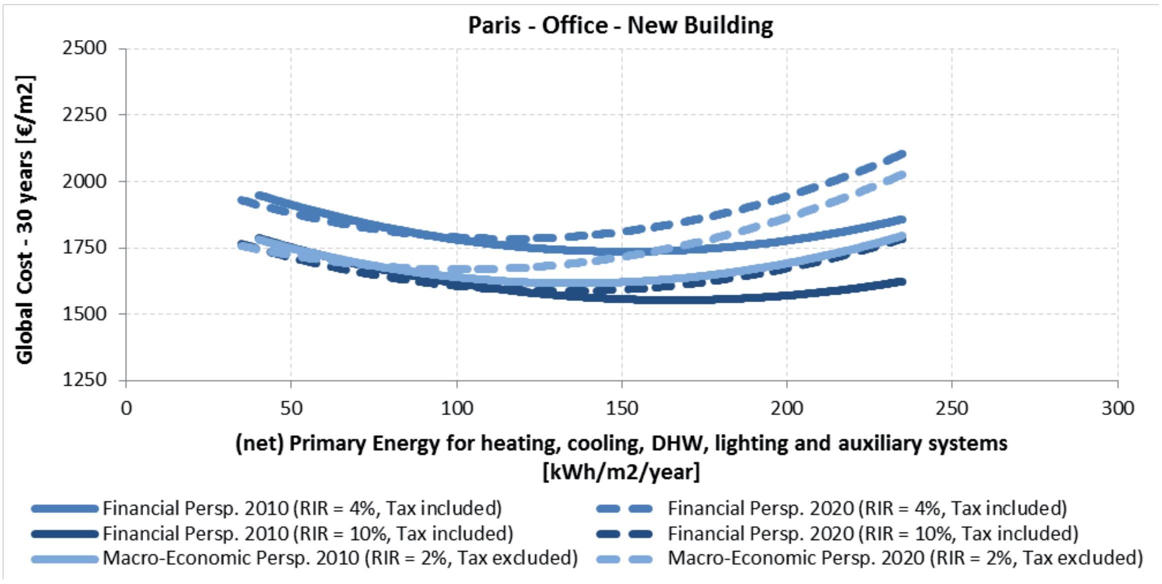

Figure 4. New building: sensitivity analysis on the lower profile of the energy/cost domain as a function of several key economic perspectives and different cost database (2010/2020).

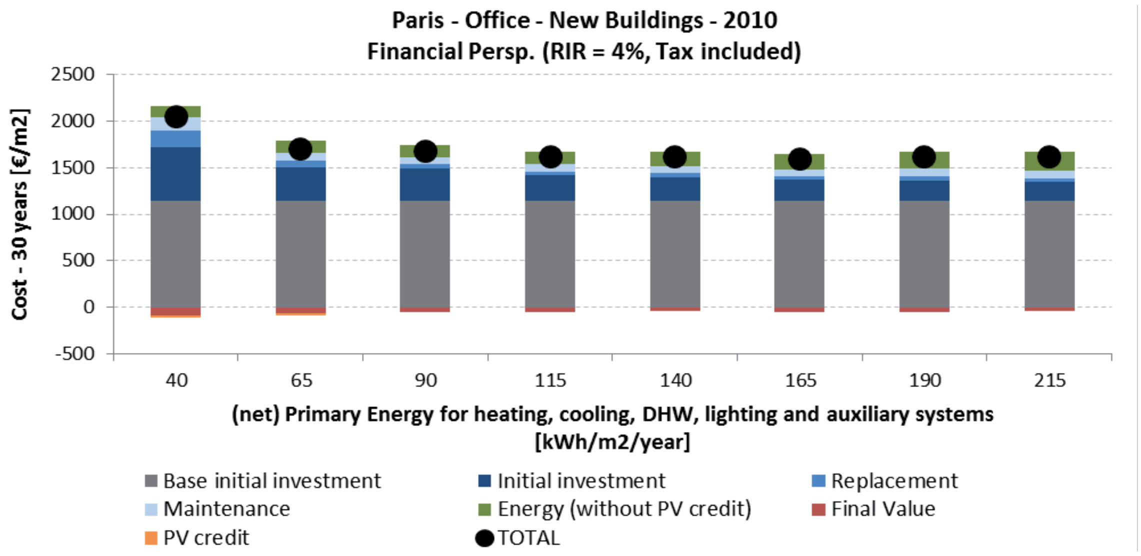

Figure 5. Disaggregation of building costs for several building variants on the lower profile of the energy/cost domain, considering a financial perspective (RIR = 4 %) and the cost data 2010.

- In northern climates harsh winters and relatively low solar irradiation make things more challenging. The envelope performance becomes even more crucial (and should be probably even more advanced than considered in our scenarios, especially in those cases where energy sources with advantageous primary energy balance are limited, such ground source heat pumps in urban centres).
- With respect to the use of renewable energy sources, the technical variants that are considered in this study are limited. In several cases other possibilities of delivering RES to buildings to cover the low residual energy needs for heating and cooling (and further reduced energy uses for lighting, office equipment and domestic appliances) might indeed be available. Off-site renewables might be considered by MS as an option for dense urban settings. Some of them might have anyway their own limitations e.g. biomass burning in specific urban situations might be impossible due to its contribution to PM10 emissions or might require relatively costly filtering at stack.
- In contrast to the limitations given with respect to RES technologies reducing losses through the building envelope as well as efficient lighting design, lighting sources and appliances are available irrespective of the building location and therefore are indispensable preconditions on the way towards nZEB.

Quality check for cost optimality calculations

The selected examples demonstrate big variety for cost optimality calculations, even if they fulfil the framework prescribed by the EU regulation. Taking into account this high degree of freedom the following section develops an approach for a quick check of the quality of cost optimality calculations. This is done in a three-steps-approach, starting with an assessment of the plausibility of results, followed by a more comprehensive evaluation of the most important input variables used and concluded by a check of possible short-coming related to the methodology applied.

STEP 1: PLAUSIBILITY CHECKS ON RESULTS OF COST OPTIMALITY CALCULATIONS

Step 1 just looks on the results of the cost optimality calculation and addresses the following topics:

- One core assumption which is confirmed by many cost optimality and life-cycle cost assessments in the building sectors says that cost curves are relatively flat in an area ranging from "conventional building" up to low-energy houses and partly also nearly-Zero-Energy-Buildings. This means that from a life-cycle cost perspective global cost differences are rather low – and in many cases insignificant. In the boundary areas – i.e. the areas of very inefficient buildings on the one hand and of energy-plus-buildings on the other hand – the cost curves, however, show a steeper increase. Example B shows that the whole "cloud" of results of a multitude of potential variants may cover a wider spectrum of cost differences. This is due to the fact, that in example B over 40,000 variants (i.e. combinations of measures) have been assessed, among which many combinations do not make sense from a technical point of view. The "cost curve" – i.e. the lower boundary of the "cloud" – shows a flat form comparable to the form of the cost curves derived in example A, where only 26 variants have been defined and assessed in an iterative way which is similar to design processes.
- The shape of the cost curve is influenced by the climatic conditions. In warmer, summer-dominated climates, the cost-optimum is shifted to the "left side", meaning that nearly-Zero-Energy-Buildings have a high chance to match the area of cost optimality. In winter-dominated climates things are in general more challenging.
- Usually the results show considerable robustness in sensitivity analysis, unless a bundle of input parameters is changed remarkably into the same direction – i.e. supporting or disadvantaging energy efficiency and RES-use.

STEP 2: QUALITY CHECK FOR INPUT PARAMETERS AND CORE ASSUMPTIONS

Based on the analysis of the driving factors from the examples several quality criteria concerning the assumptions of the most important input parameters can be derived. The quality criteria reflect the importance of the driving factors by characterising requirements in defining the assumptions of core input factors:

- Plausibility of reference building: This refers mostly to the size, shape and compactness of the selected reference building. Also the share of window area requires an evaluation of plausibility. Representativeness in a more narrow sense, however, cannot be fulfilled by only one or two reference buildings.
- Definition of variants: This check refers to the question if the analysed variants cover the most plausible packages of technical measures. This can be achieved by a permutation over all possible combinations of measures (example B). But also iterative approaches, which are more related to design processes in practice, may come up with a selection of the most plausible variants for a specific reference building (example A).
- Quality of cost data: It has to be underlined that there exist considerable cost differences also on the market, depending on region, point in time, different quality of material etc. Therefore it is important not to mix different information sources, in order to prevent unrealistic cost differences related to different performance qualities.
- For most of the other input factors, it is necessary to check if there exists a concentrated bias into one direction. This relates first of all to the discount rate, to energy starting prices and assumed future trends as well as to assumed lifetimes of the relevant buildings elements. In this respect the "spread" between discount rate and future energy price development is of crucial importance, i.e. a high energy price increase combined with a low discount rate or vice versa is less plausible than a moderate assumption on both sides.

STEP 3: METHODOLOGY CHECK

Typically one would expect that the methodology needs to be checked in first place. In practice, however, this is difficult since one would need to have a thorough look into the calculation software tools in order to detect methodological short-comings. Therefore usually only a few methodological issues can be checked by an "outsider":

- Completeness of considered cost elements: Especially maintenance cost is sometimes forgotten.
- Differentiation of life-times of building elements: Building elements have different life-times in practice and this fact has to be reflected in the cost optimality calculation. An example would be a differentiation between the life-times of the central-heating boiler and the heating distribution system (pipes and radiators).
- Provision for residual values: In this context a plausibility check is only possible, if separate sensitivity analyses are presented with variations of life-times of building elements. If residual values were not taken into account (in a correct) way, there would be no (resp. very little) changes in the results.

Summary and Conclusions

Most member states are still in the process of preparing "their" cost optimality under the EPBD regulation and comparative assessment in a broader sense is still not possible. Therefore at present it is not possible to derive a final conclusion whether the cost optimality principle will be rather a push or a brake on the way towards nearly-Zero-Energy-Buildings – and beyond.

A large share of cost optimality assessments which are available – including those presented in this paper – suggest that considerable tightening of minimum energy performance requirements can be argued also from an economic point of view. This is also true for countries such as Austria which already have relatively ambitious energy performance regulations in their building codes. Cost optimality calculations show that that a further tightening of the current level of standards could be implemented without effecting substantial overall cost increases over the life cycle.

On the other hand, since the EU regulation offers a high degree of freedom on the actual implementation of cost optimality calculations, very different results cannot be completely excluded. By assessing the influence of the most important core assumptions and input parameters this paper derives a quick check approach on the quality of cost optimality assessments which can help to understand potentially big differences in the results. The approach starts from the observation that economic arguments should not be overrated with respect to energy performance of buildings, because a large share of assessments shows rather flat curves. This means that when taking into account global costs over the whole life-cycle differences turn out to be rather low – and in many cases negligible. On the other hand, one may suspect that cost optimality assessments, that show clear economic advantages for buildings with weak energy performance, might require a comprehensive evaluation of the input parameters and other core assumptions which they apply.

References

DG Energy (2009), EU Energy Trends to 2030, Brüssel, 2009.

EU Regulation (2012), Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU (EPBD).

Haus der Zukunft (2011): Description of the research project "Innovative Gebäudekonzepte im ökologischen und ökonomischen Vergleich über den Lebenszyklus" on the website of the programme: http://www.hausderzukunft.at/results.html/id6529.

Leutgöb, Klemens; Rammerstorfer, Johannes; Jörg, Barbara; Hofer, Gerhard (2012): Analyse des kostenoptimalen Anforderungsniveaus für Wohnungsneubauten, Wien, November 2012.

Schöberl, Helmut; Lang, Christoph; Handler, Simon (2012): Ermittlung und Evaluierung der baulichen Mehrkosten von Passivhausprojekten, Projektbericht im Rahmen der Programmlinie Haus der Zukunft, Wien, August 2012.