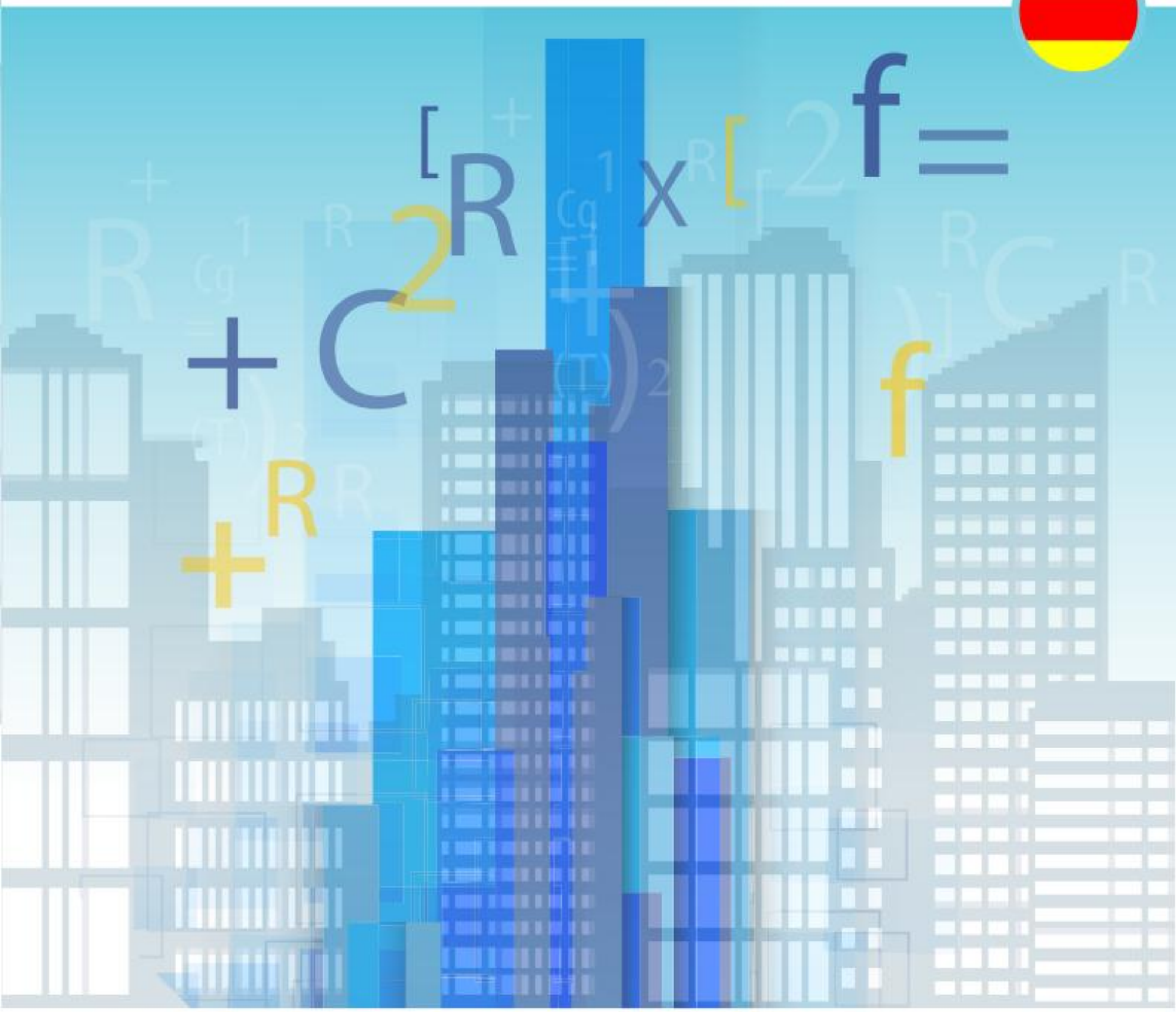
IMPLEMENTING THE COST-OPTIMAL METHODOLOGY IN EU COUNTRIES

CASE STUDY GERMANY



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1 Introduction

1.1 Aim of the study

Directive 2010/31/EU on the energy performance of buildings (recast) stipulates that Member States shall ensure that minimum energy performance requirements are set with a view to achieving at least cost-optimal levels for buildings, building units and building elements. To determine the cost-optimal levels, Member States are required to use a comparative framework methodology (cost-optimal methodology) established by the Commission and complete this framework with the relevant national parameters.

BPIE is implementing a study for providing more guidance and good practices for a proper implementation of the EPBD cost-optimality requirement within the EU Member States. The study is based on a detailed analysis of the cost-optimality approach in some selected EU Member States with the aim of:

- Proposing guidance on how to properly deal with several influential factors
- Sharing lessons learned;
- Analysing the influence of using a more realistic societal discount rate and more ambitious simulation variants/packages;
- Identifying the gap between cost-optimal and nearly zero-energy levels.

On behalf of BPIE IWU has carried out a study on cost-optimal levels for new residential buildings following the cost-optimal methodology for Germany. The methodological basis, the measures and the costs were developed in the framework of the project: "Evaluation and Further Development of EnEV 2009: Study about the Economic Framework Conditions in Housing“ on behalf of the Federal Institute for Research on Building, Urban Affairs and Spatial Development [IWU 2012].

1.2 Results of the global cost calculation

From a private financial perspective the calculated cost-optimal primary energy values of new buildings are approximately 53 kWh/m²a for the selected multi-family building (MFH) and 54 kWh/m²a for the selected single-family building (SFH). The cost optimal levels are not yet reached by the current requirements (EnEV 2009). The minimum energy performance requirements could be tightened by about 15 % to achieve cost-optimal levels and by about 25 % to achieve the same global costs as EnEV 2009. However, this gap will be closed by an EnEV recast drafted by the German government: The maximum primary energy demand shall be lowered in two steps, each time by 12.5%.

In the most cost-effective cases higher energy performance standards towards nZEB (e.g. “efficiency building 55” and “efficiency building 40”[1]) will involve increases of additional global costs between 23 €/m² and 101 €/m² compared to EnEV 2009.

The calculations from a macroeconomic perspective (without VAT and with cost of greenhouse gas emissions) show that the cost-optimal levels do not change compared to the private financial perspective (cost-optimal level 54 kWh/(m²a) for SFH and 53 kWh/(m²a) for MFH. Only the additional costs of advanced energy performance standards compared to EnEV 2009 are decreasing. From a macroeconomic perspective the “efficiency building 55” and “efficiency building 40” will involve increases of additional global costs compared to EnEV 2009 between 13 €/m² and 77 €/m² in the most cost-effective cases.

1.3 Remarks

An important influential factor for the cost-optimal methodology is the selection of input factors. The sensitivity analysis shows that changes of one input factor (discount rate, energy price development) have a certain influence on the results compared to the standards assumptions of the basic scenario. Lower discount rates and a higher energy price development are leading to lower cost-optimal primary energy values, therefore the gap to current requirements is becoming bigger and the additional costs of higher energy performance standards compared to EnEV 09 are decreasing. Higher energy performance standards are becoming more profitable or less non-profitable depending on the standard. The influence on the results is really significant if two input factors are changed simultaneously and are taking effect in the same direction e.g. a combination of a discount rate of 1 % and a high energy price development. In the frame of the cost-optimal methodology the choice of input factors is an important influential factor and should be established with care.

Other important factors for the cost-optimal levels are the initial investment costs. In contrast to existing buildings [Hinz 2010] empirically verified studies based on invoiced investment costs of energy savings measures for new buildings are currently not available for Germany. Within the project ‘Evaluation and Further Development of EnEV 2009: Study about the Economic Framework Conditions in Housing’ [IWU 2012] three architecture and engineering offices were commissioned to investigate costs for different levels of insulation and different types of heat supply systems based on actual cost statements and tenders of recent construction projects. Each office developed detailed scenarios for the given model buildings and analysed how to implement the different levels of energy performance for the different techniques. On this basis the costs were projected (similar to the standard planning process) by considering all relevant elements and devices. The resulting cost data were analysed and

[1] Funded energy performance standards of the German promotional bank KfW

averaged by IWU to determine cost functions, facilitating an easy variation of insulation thickness and building size during the economical assessment.

An alternative method to determine the costs of different energy performance standards would be to make a broad market research on new built homes in Germany. The problem is only that the energy quality of a building correlates also with other building features. For example, it may be that energy efficient buildings like passive houses are currently constructed mainly by financially strong owners. Of course, it can be assumed that these owners also install premium bathrooms, kitchens and garages or appreciate prestigious façade surfaces or roof tiles. The incremental costs of insulation could only be determined if the other price determining features were also elevated. Such a comprehensive representative survey does not yet exist in Germany. But even if it could be implemented, the question of accuracy has to be answered: Is the number of new buildings sufficiently large to determine the – compared to other features – small influence of the energy performance on the construction costs (or market price)?

Another influential factor is the reference building selection. In recent studies some adaptations of the "official" building data had to be done by IWU in collaboration with the three involved architect offices in order to define realistic planning scenarios. For the future we recommend to use model buildings designed by architects. The buildings should have rather common and simple geometries and the realisation should in principle be practicable – for all considered energy performance levels. Designs which do not take account of the basic principles of energy efficient architecture and which are not favourable to attain nZEBs should be excluded. Furthermore, plans of actually built houses could be used - with simplifications or adaptations, if necessary.

The basis of the cost optimum analysis is the energy balance calculation according to the national implementation of EPBD. The energy performance calculation includes standard assumptions of climatic conditions and user behaviour. These boundary conditions are not necessarily identical with typical or average values of the country. For example, the German asset rating calculation (EnEV 2009 / DIN V 4108-6) is based on a set-point temperature of 19°C. However, there is evidence that significantly higher temperatures can be typically found in well insulated buildings and significantly lower in poorly insulated buildings (new buildings: 20-21°C, existing not refurbished buildings: 17°C). Since the economic assessment of insulation depends on the assumed room temperature, it should be discussed if this effect should be considered in the C-O calculations. The inclusion of this effect could lead to two different results: a) the assumption of a higher room temperature level for new buildings would presumably result in an improved cost effectiveness of thermal protection in this case and b) assuming realistic room temperatures for non-refurbished old buildings would lead to lower (more realistic) energy savings and a decreasing cost effectiveness of insulation measures.

The discussion of reality based assumptions may in the future also include other boundary conditions, e.g. the shading by buildings or trees nearby (the standard assumption in the

German regulation doesn’t consider shading), the air exchange rates with and without ventilation system etc.

The economic analyses of exemplary new buildings in this study were carried out by assuming a distinct construction system. The considered buildings have masonry walls with an external insulated render system, the ceilings are assumed as concrete elements. The pitched roof of the semi-detached house is a wooden construction whereas the flat roof of the multi-family house is a concrete structure with insulation on the top [IWU 2012].

Of course, in practice, further construction systems can be found, but due to the correlation with other non-energy related costs and the associated uncertainties (see chapter 2.5) we can say that the determination of cost optima only makes sense within a given construction system but not between different types.

An official definition of nZEBs has not yet been published in Germany. Nevertheless, we can assume that the definition will be close to the standard "KfW Effizienzhaus 40" (“efficiency building 40”, primary energy demand = 40% of the requirements), which is the most ambitious level of the Federal grant programme for new buildings. Already now the standard “Effizienzhaus 40” was used in scenario calculations for the German building stock as an equivalent of the not yet exactly defined nZEB standard of new buildings for the 2020 projection. To fill the gap between the current requirements of EnEV 2009 and this nZEB level, a step by step tightening of the requirements as it is drafted in Germany seems to be the right way ahead.

Compared to typical construction costs for new buildings in Germany (1300 €/m²) the additional global costs for the most cost-effective standards towards nZEB range between 2 % and 8 %. These percentages are in a similar range as “typical fluctuations" of construction costs. Nevertheless, a tightening of the minimum energy performance requirements from EnEV 09 or from the cost-optimal level towards nZEB would be non-economical. This is in line with the EPBD but would cause problems with the German energy saving law (Energieeinsparungsgesetz EnEG), which postulates that minimum energy performance requirements have to be "economically justifiable". This is an obstacle for the implementation of the EPBD requirements to introduce nZEB levels for new buildings in 2020. After the planned tightening of requirements further improvements will be non-economic and therefore not justifiable against the German energy saving law.

By the use of the ‘cost-optimal methodology’ it is remarkable that as a result of the given flexibility (e.g. selection of reference buildings, optional discount rates, selection of variants) on the one hand and the fixed input factors and sensitivity analysis on the other hand, a great number of cost-optimal levels or cost-optimal ranges occurs. In this context it seems to be a big challenge to avoid another “painful” reporting exercise for the Member States.

Regarding the macroeconomic perspective, it can be stated that the considered costs of greenhouse gas emissions respective the assumed carbon prices from Annex II of the C-O regulation are too low to cause relevant changes in cost-optimal levels. For relevant changes in cost-optimal levels, the assumed carbon prices must be clearly higher.

There are some studies available about the internalization of external environmental costs in the construction sector [e.g.BMVBS 2010] but the investigation of external costs in construction requires still a lot of research. As long as the German energy saving law (Energieeinsparungsgesetz EnEG) postulates that minimum energy performance requirements have to be "economically justifiable", it is obvious that the private financial perspective for private investors may be seen as an appropriate basis for official cost-optimal calculations.

2 Cost-optimal methodology for new buildings

2.1 Overview

The cost-optimal methodology defines for Member States the following procedure to determine cost-optimal levels for new residential buildings[2]:

1. Definition of reference buildings
2. Selection of variants
3. Energy performance assessment
4. Global cost calculation
5. Sensitivity analysis
6. Determination of cost optimal levels

For the global cost calculation some input factors are fixed (e.g. calculation period, cost categories, starting year of the calculation, use of a discount rate of 3 %), some other have to be defined on national level (e.g. energy prices, energy price development, lifetime of buildings and building components, use of disposal costs)

The following table shows the main assumptions and input factors for the cost-optimality calculation from a private financial perspective (new buildings). The single input factors and assumptions were described in more detail within chapters 2.2 to 2.5.

[2] See Annex I [EC 2012a]

Table 1: Assumptions and input factors for the cost-optimality study in Germany (private financial perspective)

Assumptions and input factors cost-optimality study Germany (private financial perspective)	
Reference buildings	New residential buildings: 1 SFH; 1 MFH
Measures/variants/packages	Packages: Combinations of thermal protection and heat supply system
Energy performance assessment	DIN V 4108-6 together with DIN V 4701-10 – version valid for EnEV 2009 (new buildings)
Cost categories	• Investment cost • Residual value • Replacement cost • Maintenance cost • Energy cost
Calculation Method	Global cost calculation - net present value method Calculation with real terms (inflation-adjusted)
Lifetime of building components	50 years (thermal protection) / 30 years (windows) / 15 years (technical installations) according to DIN 15459 Annex A
Calculation period	30 years
Inflation	2 %/a (long-term goal ECB)
Discount rate	3.0 % (basic scenario) / 1 %
Price development for maintenance and replacement	0 %/a
Annual cost for maintenance (for technical installations)	2 % of initial investment costs
Current energy prices	7.0 Cent/kWh (gas), 5.0 Cent/kWh (wood pellets), 25.0 Cent/kWh (electricity auxiliary energy), 19.0 Cent/kWh (special tariff heat pump)
Energy price development	Low: 1.3 %/a Medium: 2.8 %/a (basic scenario) High: 4.3 %/a

2.2 Reference buildings

An exemplary single-family building (semi-detached house) and one multifamily building are considered as reference buildings. The used building data were developed in [ZUB 2010] on behalf of the Federal Ministry of Transport, Building and Urban Development (BMVBS) with the intention to provide reference buildings for the economical assessment of legal requirements. The buildings were used as model buildings in the study [IWU 2012] on behalf of BMVBS which is also the basis for the present investigation.

In this context some adaptations of the building data had to be done by IWU in collaboration with the three involved architect offices. The main changes were (for details see [IWU 2012]):

Single-family house / semi-detached building:

- Rotation by 90° to enable the installation of solar collectors (also corrected in the building picture);
- Inclusion of the top attic space in the thermal envelope: avoids problems with tightness and thermal bridging, provides a room for installation of heating and ventilation system – and is normal in new buildings (also corrected in the building picture);
- Lowering of the ground level below cellar ceiling: so the render insulation system can extend below the bottom edge of the cellar ceiling (standard solution);
- Cellar access is outside the thermal envelope: helps avoiding thermal bridging.

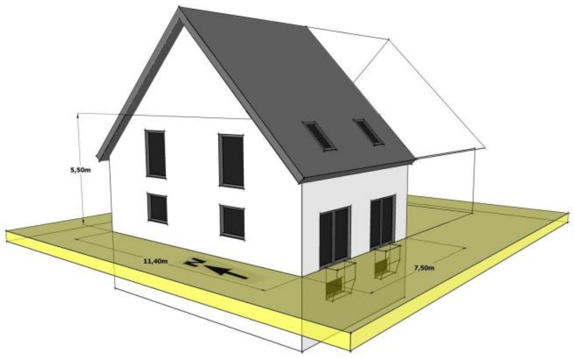
Multi-family house / apartment building:

- No neighbour building in the South: otherwise the thermal area of the walls would have been extremely small and also the costs would have been not representative due to the very high window fraction (also corrected in the building picture);
- Balconies are realised as detached static structures: avoidance of thermal bridging;
- Cellar access is outside the thermal envelope: helps avoiding thermal bridging.

The basic data of the model buildings are:

1. **Single-family building (SFH)**

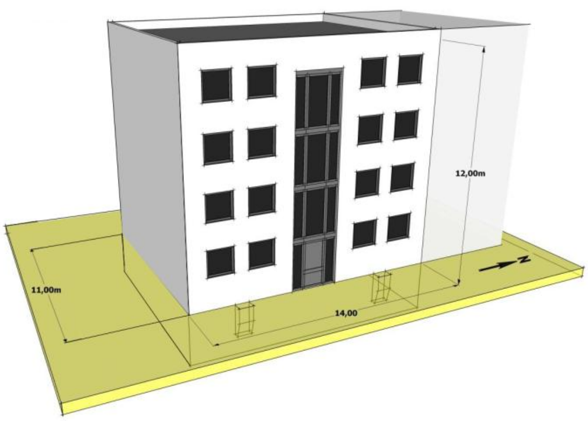
Heated volume V_e:	586 m³
Heated living space:	139 m²
Usefull floor area A_N acc. to EnEV:	187.5 m²
Surface area S:	344.5 m²
S/V_e:	0.59 m^{-1}



Picture: [ZUB 2010], modified by IWU

2. **Multifamily building (MFH)**

Heated volume V_e:	1848 m³
Heated living space:	473,0 m²
Useful floor area A_N acc. to EnEV:	591.4 m²
Surface area S:	776.0 m²
S/V_e:	0.42 m^{-1}



Picture: [ZUB 2010], modified by IWU

The thermal envelope of the model buildings had been defined without designing the interior of the buildings [ZUB 2010]. From our point of view this leads to a number of disadvantages. For example, the multi-family building has 12 apartments with a total living area of (estimated) 473 m² resulting in apartment sizes about 40 m² which is rather small. One consequence is rather high costs per m² for individual ventilation systems installed in the different apartments.

The publication of the two buildings included a table with the basic data and all thermal envelope areas as well as perspective drawings [ZUB 2010]. This turned out to not be sufficient for the architect offices to determine the costs of the different measure variants. They would have needed at least ground plans and façade views with dimensions, to determine specific lengths or areas (sizes of single windows, edge lengths of the roof areas and the facades …). So they had to make individual assumptions which may differ in some points.

In the future we recommend using model buildings designed by architects. The buildings should have rather common and simple geometries; the realisation should in principle be practicable. Also plans of actually built houses could be used - with simplifications or adaptations, if necessary.[3]

[3] Three examples of such real model buildings "re-designed" by an architect to fit the task can be found in: Loga, Tobias; Knissel, Jens; Diefenbach, Nikolaus: Energy performance requirements for new buildings in 11 countries from Central Europe – Exemplary Comparison of three buildings. Final Report; performed on behalf of the German Federal Office for Building and Regional Planning (Bundesamt für Bauwesen und Raumordnung, Bonn); in collaboration with e7 / Austria, STU-K / Czech Republic, NAPE / Poland; MDH / Sweden, SBi / Denmark, BRE / UK, BuildDesk / Netherlands, BBRI / Belgium, GLA / Luxembourg, ADEME / France; Institut Wohnen und Umwelt, Darmstadt / Germany Dec. 2008 www.iwu.de/fileadmin/user_upload/dateien/energie/werkzeuge/iwu_report_-_comp_req_new_buildings.pdf

2.3 Selection of variants

To determine the cost optimal level for new residential buildings at first six different thermal protection standards respectively combinations of insulation measures (e.g. insulation of roof, walls, cellar ceiling as well as thermally improved windows) were defined [IWU 2012]:

Table 2: Definition of thermal protection standards

1.	**EnEV 2007 HT' Max**	$\leq$ $H'_{T,zul}$ according EnEV 2007
2.	**EnEV 2009 HT' Max**	$\leq$ $H'_{T,zul}$ according EnEV 2009
3.	**EnEV 2009 U Ref**	U-Values EnEV 2009 reference building
4.	**EnEV 2009 U Ref 85%**	85% of "EnEV 2009 U Ref"
5.	**EnEV 2009 U Ref 70%**	70% of "EnEV 2009 U Ref"
6.	**EnEV 2009 U Ref 55%**	55% of "EnEV 2009 U Ref" (≈ U-values of passive houses)

The first and second levels are reflecting the thermal protection requirements (secondary condition) of the German Energy Saving Ordinances (EnEV) from 2007 (no longer valid) and 2009 (current requirement). The third level is representing the U-values given by the reference specification of the current EnEV 2009[4] (these values are used to calculate the maximum primary energy demand).

The variants 85%, 70% and 55% of "EnEV 2009 U Ref" are similar to the three different thermal protection requirements (also as secondary conditions) of the Federal funding scheme for new buildings of the German promotional bank KfW. Furthermore, the sixth level represents U-values of passive houses.

For all variants a thermal bridging supplement of 0.02 W/(m²K) is assumed which is actually easy to reach by observing the basic rules of thermal envelope planning. (Attention in case of cross-country comparisons: the value can only be compared to values determined on the basis of external dimensions of the building.)

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[4] According to the German energy saving ordinance EnEV 2009 all new buildings have to meet two requirements at the same time:

- Maximum values of the H_T/A_{env} (heat transfer coefficient by transmission divided by envelope area, tabled depending on building size and neighbour situation
- Maximum values of QP/Ac,nat (primary energy demand divided by "conditioned floor area" = a synthetic area derived from the building volume by a fixed factor) which are determined by a reference specification (German expression "reference building" omitted here to avoid confusion) consisting of a table with U-values and a heating system. The maximum primary energy demand is determined by assuming the reference specification and calculating the primary energy demand for a distinct building.

A precondition is that renewable energies are used to a certain extent – otherwise 85% of both conditions are valid.

The resulting u-values for the six thermal protection standards of both example buildings are shown in the following tables:

Table 3: U-values of selected thermal protection standards SFH

U-values		1.	2.	3.	4.	5.	6.
roof	W/(m²K)	0,35	0,30	0,20	0,17	0,16	0,09
upper ceiling	W/(m²K)	0,35	0,30	0,20	0,17	0,16	0,10
wall	W/(m²K)	0,60	0,40	0,28	0,20	0,20	0,10
cellar ceiling	W/(m²K)	0,70	0,50	0,35	0,25	0,20	0,13
windows	W/(m²K)	1,50	1,50	1,30	1,30	0,80	0,80
rooflight	W/(m²K)	1,80	1,80	1,40	1,40	1,00	1,00
front door	W/(m²K)	2,00	2,00	1,80	1,80	0,80	0,80

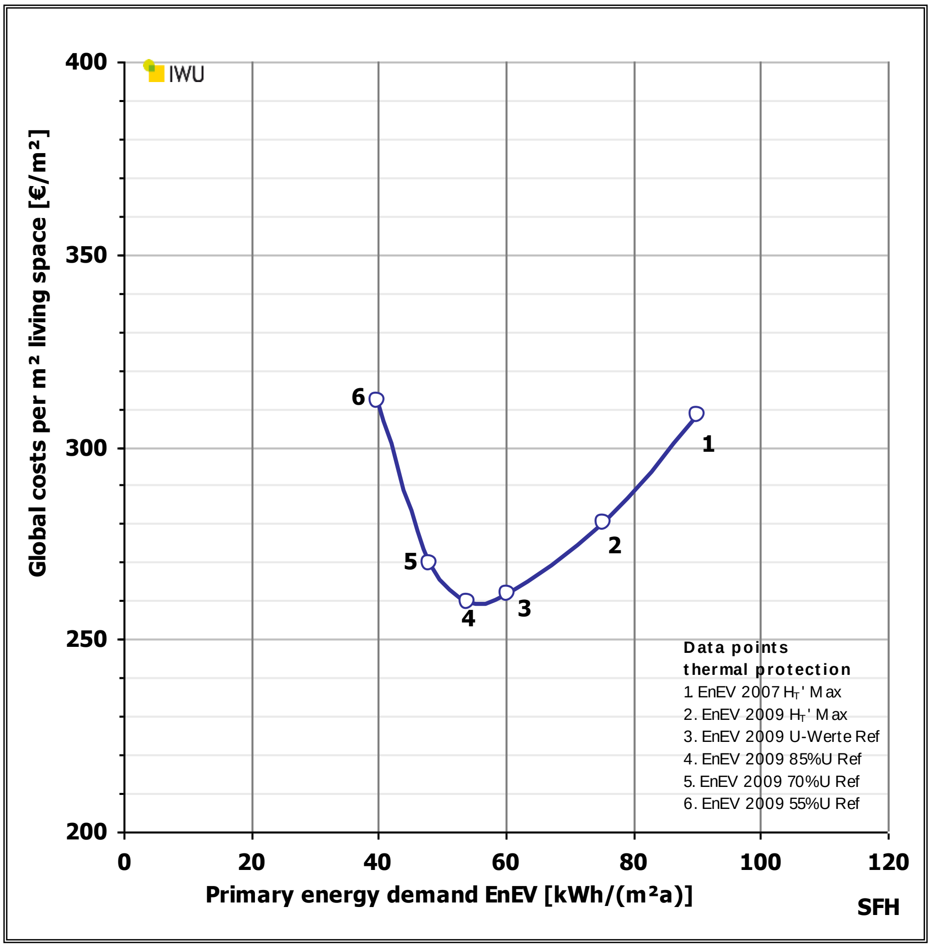
Table 4: U-values of selected thermal protection standards MFH

U-values		1.	2.	3.	4.	5.	6.
roof	W/(m²K)	0,35	0,24	0,20	0,16	0,18	0,10
upper ceiling	W/(m²K)	0,35	0,24	0,20	0,16	0,18	0,10
wall	W/(m²K)	0,57	0,32	0,28	0,18	0,20	0,12
cellar ceiling	W/(m²K)	0,70	0,35	0,35	0,25	0,25	0,15
windows	W/(m²K)	1,50	1,30	1,30	1,30	0,80	0,80
rooflight	W/(m²K)	1,80	1,40	1,40	1,40	1,00	1,00
front door	W/(m²K)	2,00	1,80	1,80	1,80	0,80	0,80

In order to facilitate the understanding of our proceeding we will in the following show the C-O calculation for the single family house with one exemplary heating system:

For the 6 thermal protection standards the primary energy demand and the global costs were calculated by assuming the installation of a gas condensing boiler with solar heating system. Figure 1 shows exemplarily the global costs per m² living space versus the primary energy demand. The global cost curve consists of 6 data points starting with a poor thermal protection standard (data point 1) and ending with an ambitious thermal protection standard (data point 6). The data points are referring to the thermal protection standards of table 2 and the resulting U-values of table 3.

Fig. 1: Example of the resulting global cost curves



For the present report the following 12 central heat supply systems were analysed [IWU 2012]. Measures based on renewable energies were also considered:

Table 5: Heat supply systems

BWK	Condensing boiler (gas)
BWK+Sol	Condensing boiler (gas) + solar heating system
BWK+WRG	Condensing boiler (gas) + ventilation system with heat recovery
BWK+Sol+WRG	Condensing boiler (gas) + solar heating system and ventilation system with heat recovery
WPE	Electric heat pump / heat source soil
WPE+Sol	Electric heat pump / heat source soil with solar heating system
WPE+WRG	Electric heat pump / heat source soil with ventilation system with heat

	recovery
WPE+Sol+WRG	Electric heat pump / heat source soil with solar heating system and ventilation system with heat recovery
HPK	Wood pellets boiler
HPK+Sol	Wood pellets boiler + solar heating system
HPK+WRG	Wood pellets boiler + ventilation system with heat recovery
HPK+Sol+WRG	Wood pellets boiler + solar heating system + ventilation system with heat recovery

In total 72 cases have been created, each defined by a combination of thermal envelope and supply system variant.

An official definition of nZEBs has not yet been published in Germany. Nevertheless, it can be assumed that the definition will be close to the standard "KfW Effizienzhaus 40" ("efficiency building 40", primary energy demand = 40% of the requirements), which is the most ambitious level of the Federal Grant Programme for new buildings. Already now the standard "Effizienzhaus 40" was used in scenario calculations for the German building stock as an equivalent of the not yet exactly defined nZEB standard of new buildings for the 2020 projection. [5]

Apart from the primary energy requirements also maximum values for the heat transfer coefficient by transmission are defined for this standard. To fulfil this requirement the U-values of opaque elements must typically be in a range of 0.10 to 0.15 W/(m²K) and that of windows at about 0.8 W/(m²K) (the actual U-values depend on the building geometry and the thermal bridging losses).

The thermal envelope quality of EB 40 is similar to that of a passive house. Due to different definitions of global requirements, the technical installations may differ from those of a passive house (for example a ventilation system with heat recovery is not mandatory in an EB 40).[6]

2.4 Energy performance assessment

For the defined packages of thermal protection standards and heat supply systems the primary energy demand and the energy use are calculated by energyware (software). The basis for the energy performance calculation is the calculation method DIN V 4108-6 in

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5 See: http://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Diefenbach_IWU_DatenbasisUndSzenarien.pdf).

6 Among the selected packages the combinations of ambitious thermal protection standards (55% of "EnEV 2009 U Ref") and ventilation systems with heat recovery are covering the passive house level.

connection with DIN V 4701-10 – version valid for EnEV 2009. Energy performance results are referring to square meters of "useful floor area" A_N according to EnEV [IWU 2012].

The basis of the cost optimum analysis is the energy balance calculation according to the national implementation of EPBD. This "Asset Rating" is based on standard assumptions of climatic conditions and user behaviour. These boundary conditions are not necessarily identical with typical or average values of the country. For example, the German asset rating calculation (EnEV 2009 / DIN V 4108-6) is based on a set-point temperature of 19°C. In well insulated German buildings much higher temperatures can typically be found (new buildings: 20-21°C, existing not refurbished buildings: 17°C)[7]. Since the economic assessment of insulation depends on the assumed room temperature it should be discussed if this effect is to be considered in the C-O calculations.

The discussion of reality based assumptions would of course also include other boundary conditions, e.g. the shading by neighboured buildings or trees (the standard assumption of the German regulation is that there is no such shading), the air exchange rates with and without ventilation system…

2.5 Global cost-calculation

For the global cost-calculation (private financial perspective) the following cost categories have to be considered:

- Initial investment costs
- Residual value
- Replacement costs
- Maintenance costs
- Energy costs
- Disposal costs (if applicable)

For the present report all costs are including VAT. Subsidies are not included. The calculation is carried out with real terms (inflation adjusted). All cost categories are discounted to the beginning of the calculation period (net present value method).

$$\mathbf{NPV}_{\text{Global costs}} = \mathbf{NPV}_{\text{Investment costs}} + \mathbf{NPV}_{\text{Replacement costs}} + \mathbf{NPV}_{\text{Maintenance costs}} + \mathbf{NPV}_{\text{Energy costs}} - \mathbf{NPV}_{\text{Residual value}}$$

[7] See analysis in: Loga, Tobias; Großklos, Marc; Knissel, Jens: Der Einfluss des Gebäudestandards und des Nutzerverhaltens auf die Heizkosten – Konsequenzen für die verbrauchsabhängige Abrechnung. Eine Untersuchung im Auftrag der Viterra Energy Services AG, Essen; IWU Darmstadt, Juli 2003 www.iwu.de/fileadmin/user_upload/dateien/energie/neh_ph/IWU_Viterra__Nutzerverhalten_Heizkostenabrechnung.pdf

Initial investment costs

Important factors for the cost-optimal levels are the initial investment costs. In contrast to existing buildings [Hinz 2010], empirically verified studies based on invoiced investment costs of energy savings measures for new buildings are not available for Germany. Within the project 'Evaluation and Further Development of EnEV 2009: Study about the Economic Framework Conditions in Housing' [IWU 2012] three architecture and engineering offices were commissioned to investigate costs for thermal protection measures and energy saving installations based on actual cost statements and tenders of recent construction projects. The resulting up to date cost functions and cost data can be used for a broad range of thermal protection standards and for residential buildings of different sizes (see in detail annex 1).

Residual value

A residual value is considered for thermal protection measures (lifetime 50 years according to DIN 15459 Annex A). The residual value is determined by a straight-line depreciation of the initial investment costs of the building element to the end of the calculation period (residual value 40 % after 30 years) and discounted to the beginning of the calculation period (residual value 16.5 % for discount rate 3 %). For windows (lifetime 30 years according to DIN 15459 Annex A) neither replacement costs nor a residual value is considered.

Replacement costs

Replacement costs are considered for technical installation (lifetime 15 years according to DIN 15459 Annex A) by the use of a replacement factor (1.64 for discount rate 3 %).

Maintenance costs

Annual maintenance costs for technical installations are established at 2 % of the initial investment costs.

Energy costs

Energy costs for heating and hot water are calculated with the results of the energy performance assessment and the assumptions regarding the current energy prices for gas, wood pellets and electricity and the assumed energy price development (see table 1). Energy costs are referred to the square meter living space.

Disposal costs

Disposal costs are generally not considered because no reliable data are available. Furthermore, in the case of new buildings the lifetime of the building is more than 50 years. In this case disposal costs are marginal due to discounting (see sensitivity analysis).

Sensitivity analysis

A sensitivity analysis is performed on the discount rates and the energy performance development for the private financial perspective. Furthermore, disposal costs are exemplary considered for one reference building and thermal protection measures. The disposal costs are assumed to an overall percentage (30 %) of the initial investment costs.

Discount rate and energy price development

As a standard assumption a discount rate of 3 % (real) is used both for the private financial and the macroeconomic perspective. This discount rate was accepted in the framework of 'Evaluation and Further Development of EnEV 2009: Study about the Economic Framework Conditions in Housing' [IWU 2012]. The discount rates reflect the actual costs of capital for long-term mortgages or in case of self-financing the expected minimum return on investment. As alternative discount rate 1 % (real) is used for the sensitivity analysis. High discount rates mentioned in [EC 2010] reflecting a high risk aversion of individuals are in our opinion not suitable for calculating cost optimal levels of legal minimum energy performance requirements for new buildings.

Three scenarios of energy price development are considered. The low scenario (1.3 %/a real) is often used in the German national context e.g. for the energy conception of the Federal Government. The medium scenario (2.8 %/a real) reflects the EU energy price projections to 2030 [EC 2012b] and is used as basic scenario for the present study. The high scenario (4.3 %/a real) assumes a high energy price rise in the future like it was observed in the last years (e.g. from 2000 to 2010 5 %/a real).

Regarding the effects of discount rate and energy price development the following can be confirmed:

- Future energy costs per single time period are always increasing if the assumed energy price development in real terms (inflation adjusted) is higher than 0 %/a.
- The net present value of energy costs in every single future time period is lower than the energy costs today (period 0) and decreases over time if the discount rate is higher than the assumed energy price development (e.g. discount rate 3 %; energy price development 1 %).
- The net present value of energy costs in every single future time period is higher than the energy costs today (period 0) and increases over time if the discount rate is lower

than the assumed energy price development (e.g. discount rate 1 %; energy price development 3 %).

Further influence factors (not considered)

According to the cost optimal methodology framework the *planning costs* could be considered in the initial investment costs. In case of design and construction site management by an architect there is a respective fee in Germany which depends on the cost calculation. For each € of increasing building costs, the planning costs are growing automatically. This kind of planning costs can, in principle, be considered in the economic analyses by defining a percentage supplement on the investment costs. On the other hand, there are many cases where an individual design of a single building (paid on the basis of architectural regulations) does not happen, for example, in case of a realisation by developers or in case of prefabricated buildings. Because of scale effects in case of repeated implementation of similar construction types it can be assumed that in this case the planning costs do not depend on the insulation standards.

The economic analyses of exemplary new buildings in this study were carried out by assuming a distinct *construction system*. The considered buildings have masonry walls with an external insulated render system, the ceilings are assumed as concrete elements. The pitched roof of the semi-detached house is a wooden construction whereas the flat roof of the multi-family house is a concrete structure with insulation on the top [IWU 2012].

Of course, in practice, further construction systems can be found, especially:

- Light frame structures of various types (prefabricated buildings, constructed by use of wooden frames, insulation, and plasterboards / wooden boards, timber frame buildings, log houses, …);
- Masonry of light honeycomb bricks, porous concrete or other light bricks without additional insulation;
- Two layers of massive masonry with insulated cavity.
- …

Within one of these construction systems the investment costs - as a function of the thermal quality of the building elements- can be determined. This analysis is notably easy in cases where the insulation thicknesses varies only (e.g. masonry + insulation, concrete flat roof + insulation) and the statical structure remains untouched. Of course, the (typically very low) additional costs of more extensive element junctions and mounting parts (broader window sills, rainwater pipe mounts …) must be considered. If more complex structures are used – especially wooden elements (steep roofs, light frame walls …) – the precise realisation of the construction will typically change with the insulation thickness. In this case, the examination of costs requires a distinct planning of the details of the construction. This is in principle possible, but attention has to be paid to the fact that such different constructions have different properties also with respect to other qualities (e.g. in case of the light frame constructions, if there is an insulated layer in front of the airtight plane for installation of cables and pipes).

Furthermore, there are – especially in case of lightweight constructions – significantly different possibilities to reach a pre-set U-value, depending on the priority and experience of the designer. In consequence, the uncertainty of the costs determined by U-value variation is much higher if complex construction elements are assumed (see also [IWU 2012].

The incremental costs of improved insulation of complex construction elements is already difficult to determine, but a cost comparison of whole buildings realised by different construction systems with different insulation standards does not seem to be reasonable with respect to practicability and accuracy. It would be necessary to make parallel designs of different structure types for the considered model buildings. However, we have to realise that the uncertainties of the total costs of a building (the absolute values), are much higher than the actual quantity because they are depending on various influences. Already if different weather protection systems are used for the façade (render, clinker bricks, wooden boards, cement boards …) the cost differences can be higher than the cost variations of different insulation thicknesses of the current requirement and that of a passive house. Reliable cost optimal standards can practically not be determined in this way, since also the monetary assessment of different appearances and maintenance efforts are affected. To conclude, we can say that the determination of cost optimality does only make sense within a construction system but not between different types.

An alternative method to determine the costs of different energy performance standards would be to make a broad market research on newly built homes in Germany. The sole problem is that the energy quality of a building correlates also with other building features. For example, it may be that energy efficient buildings like passive houses are currently constructed mainly by financially strong owners. Of course, it can be assumed that these owners also install premium bathrooms, kitchens and garages or appreciate prestigious façade surfaces or roof tiles. The incremental costs of insulation could only be determined if the other price determining features were also elevated. Such a comprehensive representative survey does not yet exist in Germany. But even if it could be implemented, the question of accuracy needs to be answered: Is the number of new buildings sufficiently large to determine the – compared to other features – small influence that energy performance has on construction costs (or market price)?

3 Cost-optimal levels for new buildings

3.1 Private financial perspective

Heat supply systems with condensing boiler (gas)

In the following global cost curves for heat supply systems with condensing boiler (gas) are presented for the medium energy price development. Figure 2 shows the global costs per m² living space versus the primary energy demand for the SFH. As a reference, value global costs of 0 €/m² were determined for a new SFH with a thermal protection standard and a condensing boiler with solar heating system according to EnEV 09. All other global cost values were calculated with the help of differential costs taking into account all the cost categories of chapter 2.5.

Without considering the existing German legislation the cost-optimal level (primary demand approx. 69 kWh/(m²a)) is described by a thermal protection standard according to the u-values of the reference building of EnEV 2009 combined with a condensing boiler as heat supply system (4. data point of the lower curve – “BWK”).

The whole curve “BWK” is not in line with the existing German legislation for new buildings – in particular the renewable energies and heat law (EEWärmeG) (see explanations below).

The vertical red line marks the permissible primary energy demand according to EnEV 2009 (main requirement – for the SFH approx. 70 kWh/(m²a)). Furthermore, a requirement concerning the thermal protection of the building has to be considered (additional requirement marked by the second data point of the curves). As a result, all intersections of the global costs curves with the vertical red line are marking the legal minimum energy performance requirements if the second data point of the curves is on the right hand of the red line. In these cases the main and the additional requirement of the EnEV 2009 are fulfilled.

If the second data point of the curves is on the left hand of the red line e.g. in the case of the upper curve – “BWK+Sol+WRG” the vertical red line is not the minimum energy performance requirement because the additional requirement concerning the thermal protection is not fulfilled. In this case, the second data point marks the minimum energy performance requirements (approx. 63 kWh/(m²a) primary energy demand).

At the beginning of 2009 the EEWärmeG was introduced. This ordinance defines the use of renewable energies or comparable efficient technologies for new buildings e.g. the use of solar heating systems. Without renewable or comparable efficient systems a shortfall of 15 % of the primary energy limit of EnEV 2009 is required (in the case of SFH with condensing boiler a primary energy demand of approx. 60 kWh/m²a has to be reached by better thermal protection). For the SFH with condensing boiler (“BWK”) minimal lower global costs are resulting compared to “BWK+Sol”. In the case of the MFH (Figure 3) the requirements of EnEV and EEWärmeG (primary energy demand 15 % lower than approx. 61 kWh/(m²a)) cannot be fulfilled without solar heating systems even with the best thermal protection measures. As a consequence, in the following, the global cost minimum according to EnEV 09/EEWärmeG is described only by the curve “BWK+Sol”.

Fig. 2: Global costs SFH / heat supply systems with condensing boiler (gas) (medium energy price development)

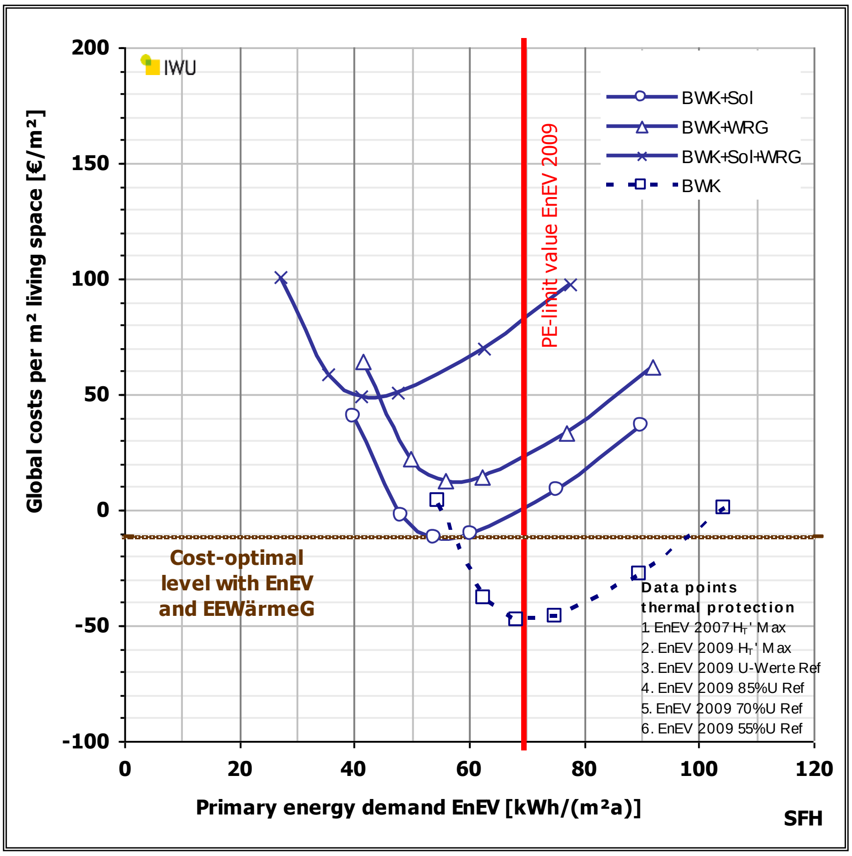
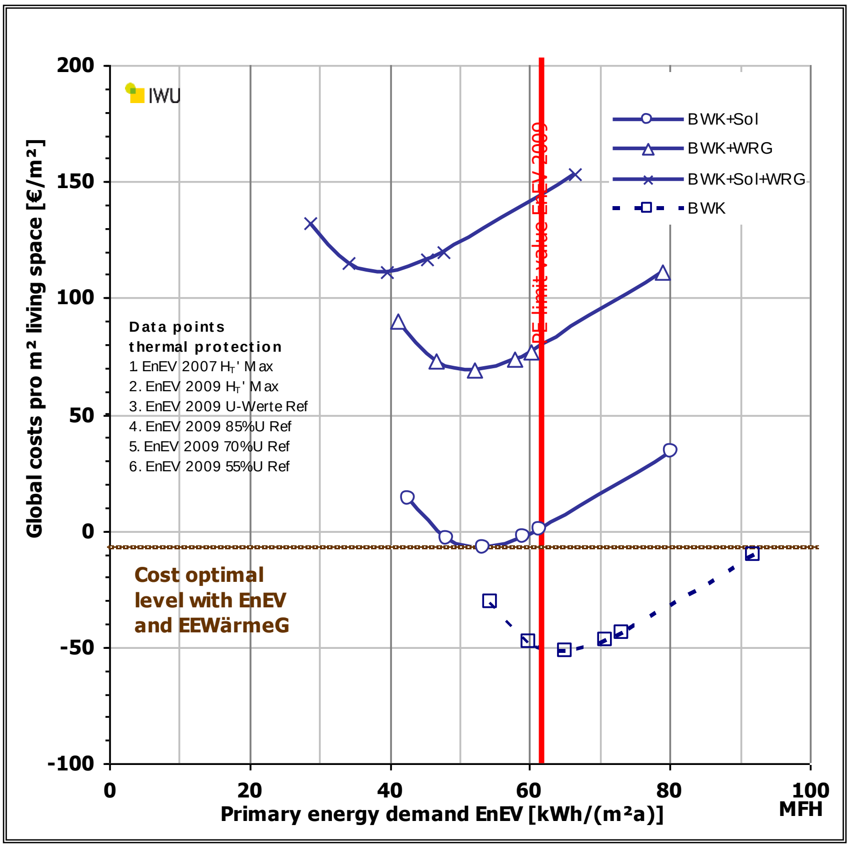


Fig. 3: Global costs MFH / heat supply systems with condensing boiler (gas) (medium energy price development)



All heat supply systems

Figure 4 and Figure 5**Error! Reference source not found.** show the global costs per m² iving space versus the primary energy demand for the SFH and the MFH for all heat supply systems (medium energy price development). The curve “BWK” is not shown due to the above mentioned reasons.

Fig. 4: Global costs SFH / all heat supply systems (medium energy price development)

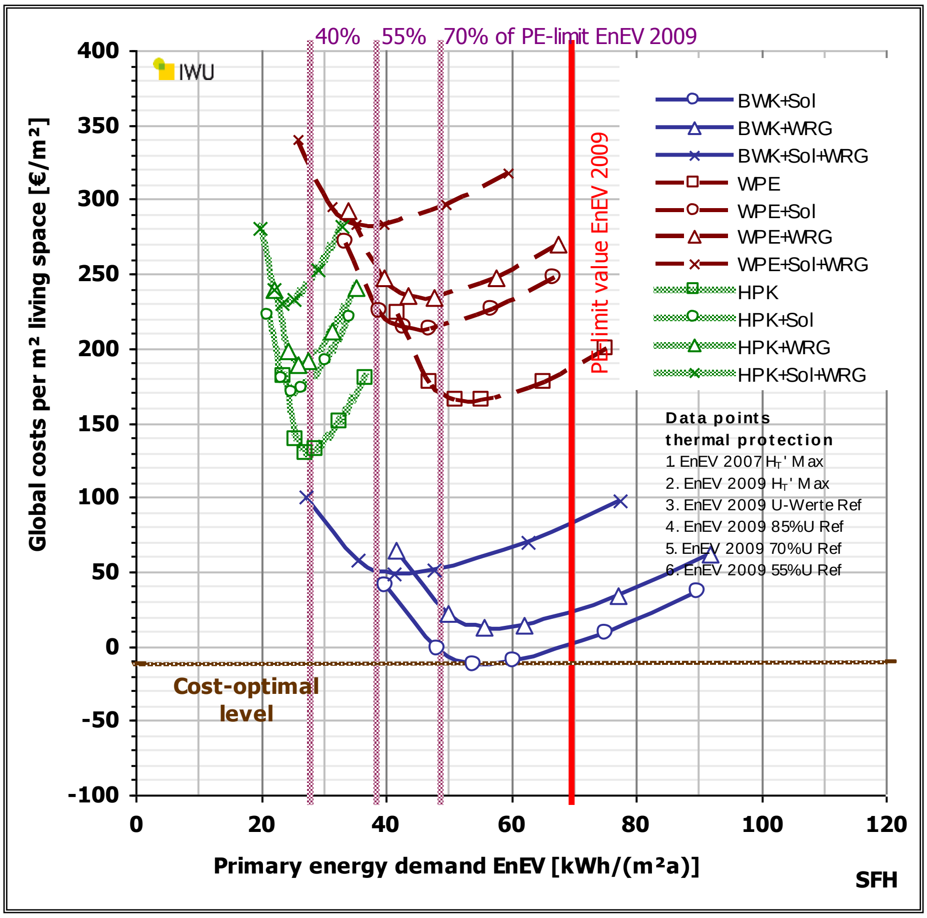
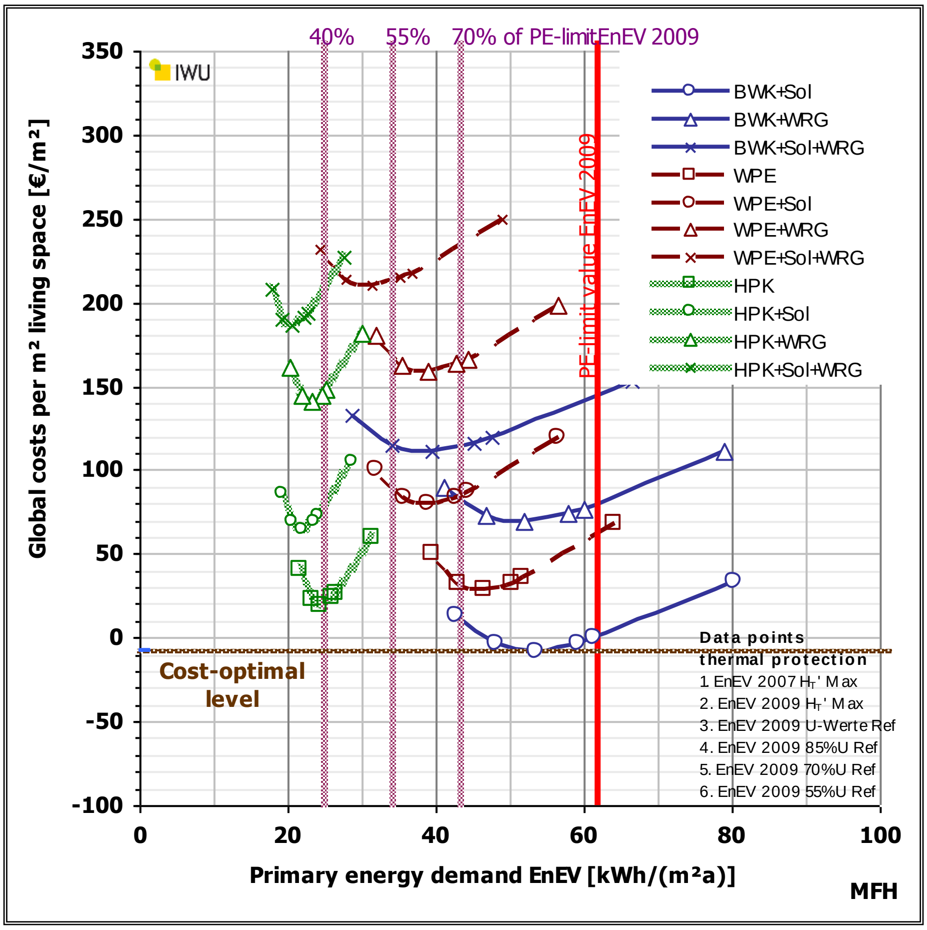


Fig. 5: Global costs MFH / all heat supply systems (medium energy price development)



The figures 4 and 5 show:

- The cost-optimal level for the SFH is represented by a thermal protection standard according to 85% of the u-values of the reference building of EnEV 2009 combined with a condensing boiler with solar heating system (4. data point of the curve – BWK+Sol / primary demand approx. 54 kWh/(m²a)).
- The cost-optimal level for the MFH is represented by a thermal protection standard according to 85 % of the u-values of the reference building of EnEV 2009 combined with a condensing boiler with solar heating system (4. data point of the curve – BWK+Sol / primary demand approx. 53 kWh/(m²a)).

- Combinations of thermal protection measures with wood pellet boilers or electric heat pumps are showing nearly comparable global costs in both reference buildings. The global costs are higher than those of combinations of thermal protection measures and condensing boilers, but the primary energy demand values are lower especially for heat supply systems with wood pellet boilers. The global cost differences are more significant in the SFH than in the MFH (due to lower investment costs per m² for wood pellet boilers and electric heat pumps in the MFH; see also table 15 in Annex 1).
- The current minimum energy performance requirements of EnEV 2009 for new buildings do not yet achieve the cost-optimal levels. Compared to EnEV 2009 the cost-optimal levels are leading to decreases of the global costs by about 12 €/m² (SFH) and 8 €/m² (MFH) (see also table 7 below).
- The minimum energy performance requirements could be tightened by about 13 % (MFH) and 23 % (SFH) to achieve cost-optimal levels (see table 6) and by about 25 % (MFH) to 30 % (SFH) to achieve the same global costs than EnEV 2009.

Table 6: Comparison table for new buildings (private financial perspective)

Reference building	Cost-optimal level [kwh/m²a]	Current requirements (EnEV 09) [kwh/m²a]	Gap [kwh/m²a] (%)
SFH	54	70	16 (23%)
MFH	53	61	8 (13%)

Energy performance standards towards nZEB

For the reference building SFH (see figure 4) energy performance standards towards nZEB can be identified as follows:

- Efficiency building 55: primary energy demand at least 55 % of the requirements of EnEV 2009 and thermal protection standard at least 70% of “EnEV 2009 U Ref”. This standard is achieved by the 5. and 6. data points of the curves “BWK+Sol+WRG”, “WPE+Sol+WRG”, “WPE+Sol”, “HPK”, “HPK-Sol”, “HPK+WRG”, “HPK+Sol+WRG”, and the 6. data point of the curve “WPE+WRG”.
- Efficiency building 40: primary energy demand at least 40 % of the requirements of EnEV 2009 and thermal protection standard 55% of “EnEV 2009 U Ref”. This standard is achieved only by the 6. data points of the curves “BWK+Sol+WRG”, “WPE+Sol+WRG”, “HPK”, “HPK-Sol”, “HPK+WRG”, “HPK+Sol+WRG”.

For the reference building MFH (see figure 5) energy performance standards towards nZEB can be identified as follows:

- Efficiency building 55: primary energy demand at least 55 % of the requirements of EnEV 2009 and thermal protection standard at least 70% of “EnEV 2009 U Ref”. This standard is achieved by the 5. and 6. data points of the curves “BWK+Sol+WRG”, “WPE+Sol+WRG”, “HPK”, “HPK-Sol”, “HPK+WRG”, “HPK+Sol+WRG”, and the 6. data points of the curves “WPE+WRG” and “WPE+Sol”.

- Efficiency building 40: primary energy demand at least 40 % of the requirements of EnEV 2009 and thermal protection standard 55% of "EnEV 2009 U Ref". This standard is achieved only by the 6. data points of the curves "WPE+Sol+WRG", "HPK", "HPK-Sol", "HPK+WRG", "HPK+Sol+WRG".

To realize the energy performance standard „passive house" (PH) combinations of ambitious thermal protection measures (thermal protection standard 55% of "EnEV 2009 U Ref") and heat supply systems with ventilation systems and heat recovery are necessary. The passive house level is achieved both in SFH and MFH by the 6. data points of the curves "BWK+WRG", "BWK+Sol+WRG", "WPE+WRG", "WPE+Sol+WRG", "HPK+WRG", "HPK+Sol+WRG".

Increases of global costs towards nZEB

As steps towards "nearly Zero-Energy Buildings (nZEB)" the efficiency buildings 55 (EB 55) and 40 (EB 40) are discussed for both reference buildings.

In the following, the additional costs of nearly zero-energy levels compared to the current requirements of EnEV 09 will be identified. Among the possible variants mentioned above only the most cost-effective combinations of thermal protection standard and heat supply system are presented. The additional costs are calculated as difference costs between the global costs for the better energy performance standards and the global costs for EnEV 09 (see in detail tables 17 and 18 of Annex 3):

- Reference building SFH: The energy performance standard „efficiency building 55" can be achieved in the most cost-effective way by a combination of ambitious thermal protection measures and a condensing boiler with solar heating system and ventilation system with heat recovery (5. data point of the curve "BWK+Sol+WRG"). The additional global costs compared to EnEV 09 are about 58 €/m². With the same heat supply system and once more improved thermal protection measures also the energy performance standard „efficiency building 40" can be achieved (6. data point of the curve "BWK+Sol+WRG"). The additional global costs compared to EnEV 09 are about 101 €/m² in this case.
- Reference building MFH: The energy performance standard „efficiency building 55" can be achieved in the most cost-effective way by a combination of ambitious thermal protection measures and a wood pellet boiler (5. data point of the curve "HPK"). The additional global costs compared to EnEV 09 are only round about 23 €/m². With the same heat supply system and once more improved thermal protection measures also the energy performance standard „efficiency building 40" can be achieved (6. data point of the curve "HPK"). The additional global costs compared to EnEV 09 are only about 41 €/m² in this case.
- In the case of SFH the additional global costs of a "passive house" (PH) compared to EnEV 09 are at least 64 €/m² for a combination of ambitious thermal protection measures with a condensing boiler and ventilation system with heat recovery (6. data point of the curve "BWK+WRG"). In the case of MFH the additional global costs of a "passive house" compared to EnEV 09 are at least 133 €/m² for a combination of

ambitious thermal protection measures with a condensing boiler and ventilation system with heat recovery (6. data point of the curve “BWK+WRG”)[8].

Table 7: Increases of global costs towards nZEB compared to EnEV 09 (medium energy price development)

Reference building	“Cost-optimal level” to EnEV 09	“Efficiency Building 55“ to EnEV 09	“Efficiency Building 40“ to EnEV 09
SFH	-12 €/m²	58 €/m²	101 €/m²
MFH	-8 €/m²	23 €/m²	41 €/m²

Compared to typical construction costs for new buildings in Germany (1300 €/m²) the additional global costs for the most cost-effective standards towards nZEB range between 2 % and 8 % compared to EnEV 09. These percentages are in a similar range as “typical fluctuations" of construction costs. Nevertheless, a tightening of the minimum energy performance requirements from EnEV 09 or the cost-optimal level[9] towards nZEB would be non-economical (higher global costs). This is in line with the EPBD but would cause problems with the German energy saving law (Energieeinsparungsgesetz EnEG), which postulates that minimum energy performance requirements have to be "economically justifiable". This is an obstacle for the implementation of the EPBD requirements to introduce nZEB levels for new buildings in 2020. After the planned tightening of requirements (the maximum primary energy demand shall be lowered in two steps, each by 12.5%) further improvements will be non-economic and therefore not justifiable with respect to the German energy saving law.

3.2 Macroeconomic perspective

Following the cost-optimal methodology [EC 2012a] Member States have to calculate the cost-optimal level both from a private financial and a macroeconomic perspective. After the calculation MS have to decide for one of these perspectives.

The following calculations from a macroeconomic perspective are based on the basic scenarios (discount rate 3%; medium energy price development) from table 1. Compared to the main assumptions of the private financial perspective the following changes for the calculations are made:

- All cost categories exclude VAT (19 %)
- Cost of greenhouse gas emissions are considered in addition

[8] The additional costs of a passive house are clearly higher for the selected MFH compared to the SFH due to higher initial investment costs for a ventilation system with heat recovery in a multi-family building with many small apartments (see also Annex 1)

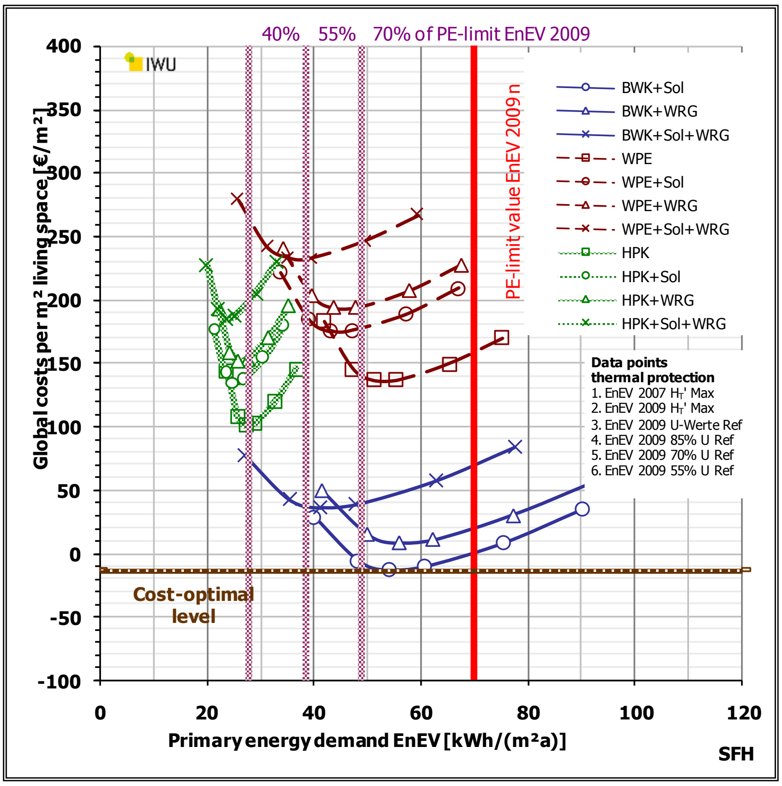
[9] The global costs of nZEB standards compared to the cost-optimal level are about 12 €/m² (SFH) and 8 €/m² (MFH) higher than in table 7.

To calculate the greenhouse gas emissions from the final energy values, the following CO_2-factors[10] are used:

- Gas: 242 [g/kWhEnd]
- Wood pellets: 41 [g/kWhEnd]
- Electricity: 633 [g/kWhEnd]

To calculate the cost of greenhouse gas emissions solely for the years of the calculation period, the carbon prices from Annex II of the C-O regulation are used [EC 2012a]: EUR 20 per tonne until 2025, EUR 35 until 2030 and EUR 50 beyond 2030. The resulting cost of greenhouse gas emissions per year were discounted to the beginning of the calculation period (net present value method).

Fig. 6: Global costs SFH / all heat supply systems (macroeconomic perspective; medium energy price development)



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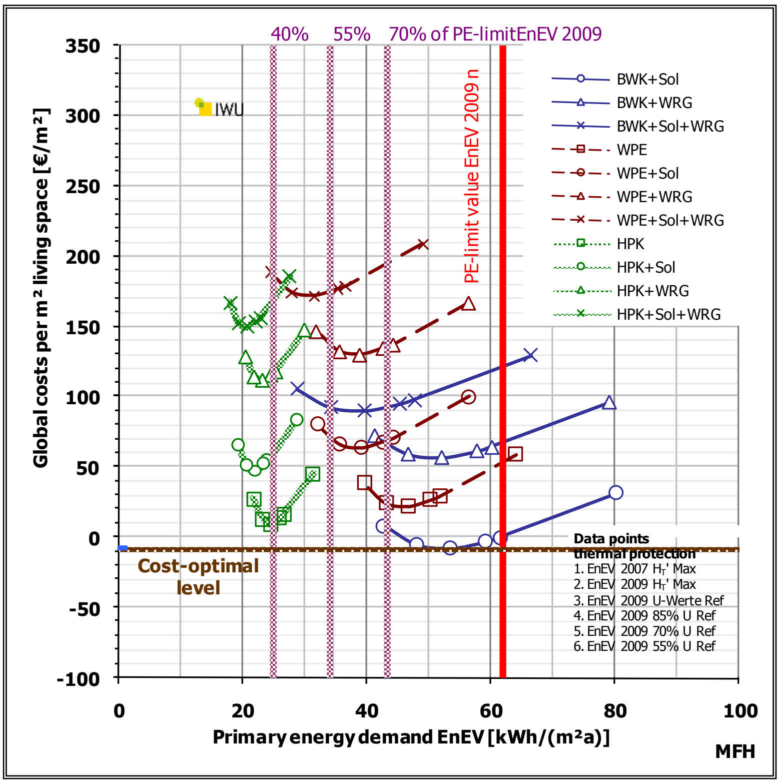
10 see http://www.iwu.de/fileadmin/user_upload/dateien/energie/werkzeuge/kea.pdf

Fig. 7: Global costs MFH / all heat supply systems (macroeconomic perspective; medium energy price development)



The figures are showing that the cost-optimal levels do not change compared to the private financial perspective (cost-optimal level 54 kWh/(m²a) for SFH and 53 kWh/(m²a) for MFH). The considered cost of greenhouse gas emissions respect the assumed carbon prices from Annex II of the C-O regulation but are too low to cause changes in cost-optimal levels.

Only the additional costs of advanced energy performance standards compared to EnEV 09 are decreasing from a macroeconomic perspective (see table below and tables 19 and 20 of Annex 3).

Table 8: Increases of global costs towards nZEB compared to EnEV 09 (macroeconomic perspective)

Reference building	"Cost-optimal level" to EnEV 09	"Efficiency Building 55" to EnEV 09	"Efficiency Building 40" to EnEV 09
SFH	-13 €/m²	43 €/m²	77 €/m²
MFH	-8 €/m²	13 €/m²	27 €/m²

In the case of SFH the additional global costs of a "passive house" compared to EnEV 09 are decreasing to 49 €/m² (6. data point of the curve "BWK+WRG"). The additional global costs of a "passive house" in the case of MFH decrease to 72 €/m² (6. data point of the curve "BWK+WRG").

3.3 Sensitivity analysis

A sensitivity analysis is performed on the discount rates and the energy performance development exemplary from the private financial perspective. In the following, the results of the sensitivity analysis regarding the cost-optimal levels and the additional costs of energy performance standards towards nZEB are presented (for detailed figures see Annex 4). A cost-optimal range is presented if the cost differences between two "cost-optimal levels" are < 1 €/m². The most cost-effective variants towards nZEB do not change compared to the basic scenario.

Discount rate

As alternative discount rate 1 % (real) is used. A lower discount rate means that all future cost categories as well as the residual value are increasingly taken into consideration within the NPV calculation compared to the basic scenario. In sum, for a discount rate of 1 % the global costs are increasing but the cost-optimal levels are moving in the direction of lower primary energy values, therefore the gap to current requirements of EnEV 09 is becoming bigger and the additional costs of higher energy performance standards compared to EnEV 09 are decreasing (higher energy performance standards are becoming more profitable or less non-profitable depending on the standard).

The results of the sensitivity analysis with a discount rate of 1 % are presented in tables 9 and 10.

Table 9: Results of sensitivity analysis discount rate SFH (medium energy price development)

DISCOUNT RATE		1 %	3 % (BASIC SCENARIO)
Cost-optimal level	[kWh/m²a]	48-54	54
Gap to EnEV 09	[kWh/m²a] (%)	22-16 (31%-23%)	16 (23%)
Additional costs CO to EnEV 09	[€/m²]	-31	-12
Additional costs EB 55 to EnEV 09	[€/m²]	+34	+58
Additional costs PH to EnEV 09	[€/m²]	+23	+65
Additional costs EB 40 to EnEV 09	[€/m²]	+59	+101

For the SFH the cost-optimal level is now described both of the 4. data point of the curve "BWK+Sol" and the 5. data point of the curve "BWK+Sol" (cost-optimal range from 48-54 kWh/(m²a); the 4. data point (54 kWh/(m²a)) has minimal lower global costs < 1 €/m²)). The additional costs of better energy performance standards (EB 55, EB 40, PH) are decreasing compared to EnEV 09 (see in detail Annex 3 and 4: tables 17 and 25).

Table 10: Results of sensitivity analysis discount rate MFH (medium energy price development)

DISCOUNT RATE		1 %	3 % (BASIC SCENARIO)
Cost-optimal level	[kWh/m²a]	48	53
Gap to EnEV 09	[kWh/m²a] (%)	13 (21%)	8 (13%)
Additional costs CO to EnEV 09	[€/m²]	-20	-8
Additional costs EB 55 to EnEV 09	[€/m²]	+18	+23
Additional costs EB 40 to EnEV 09	[€/m²]	+26	+41
Additional costs PH to EnEV 09	[€/m²]	+120	+133

For the MFH the cost-optimal level moves from the 4. data point of the curve "BWK+Sol" to the 5. data point of the curve "BWK+Sol" (cost-optimal level 48 kWh/(m²a)). The additional costs of better energy performance standards (EB 55, EB 40, PH) are also decreasing compared to EnEV 09 (see in detail Annex 3 and 4: tables 18 and 26).

Energy price development

Beside the basic scenario (2.8 %/a) two further scenarios of energy price development are considered (see in detail Annex 4: tables 21, 22, 23 and 24).

A high energy price development (4.3 %/a) means that the net present value of future energy costs is increasing compared to the basic scenario but the cost-optimal levels are moving in the direction of lower primary energy values, the gap to current requirements of EnEV 09 is becoming bigger and the additional costs of higher energy performance standards compared to EnEV 09 are decreasing (higher energy performance standards are becoming more profitable or less non-profitable depending on the standard).

A low energy price development (1.3 %/a) means that the net present value of future energy costs is decreasing compared to the basic scenario but the cost-optimal levels are moving in direction of higher primary energy values, the gap to current requirements of EnEV 09 is becoming smaller and the additional costs of higher energy performance standards compared to EnEV 09 are increasing (higher energy performance standards are becoming less profitable or more non-profitable depending on the standard).

The results for SFH and MFH are shown in tables 11 and 12.

Table 11: Results of sensitivity analysis energy price development SFH (discount rate 3 %)

ENERGY PRICE DEVELOPMENT		1.3 % (REAL)	2.8 % (REAL) (BASIC SCENARIO)	4.3 % (REAL)
Cost-optimal level	[kWh/m²a]	60	54	54
Gap to EnEV 09	[kWh/m²a] (%)	10 (14%)	16 (23%)	16 (23%)
Additional costs CO to EnEV 09	[€/m²]	-2	-12	-22
Additional costs EB 55 to EnEV 09	[€/m²]	+81	+58	+37
Additional costs PH to EnEV 09	[€/m²]	+84	+65	+47
Additional costs EB 40 to EnEV 09	[€/m²]	+127	+101	+74

High energy price development SFH: The cost-optimal level is described still by the 4th data point of the curve “BWK+Sol” (cost-optimal level 54 kWh/(m²a)). The additional costs of better energy performance standards (EB 55, EB 40, PH) are decreasing compared to the basic scenario.

Low energy price development SFH: The cost-optimal level moves to the 3th data point of the curve “BWK+Sol” (cost-optimal level 60 kWh/(m²a)). The additional costs of better energy performance standards (EB 55, EB 40, PH) are increasing compared to the basic scenario.

Table 12: Results of sensitivity analysis energy price development MFH (discount rate 3 %)

ENERGY PRICE DEVELOPMENT		1.3 % (REAL)	2.8 % (REAL) (BASIC SCENARIO)	4.3 % (REAL)
Cost-optimal level	[kWh/m²a]	53	53	48-53
Gap to EnEV 09	[kWh/m²a] (%)	8 (13%)	8 (13%)	13-8 (21%-13%)
Additional costs CO to EnEV 09	[€/m²]	-4	-8	-12
Additional costs EB 55 to EnEV 09	[€/m²]	+22	+23	+24
Additional costs EB 40 to EnEV 09	[€/m²]	+42	+41	+39
Additional costs PH to EnEV 09	[€/m²]	+147	+133	+114

High energy price development MFH: The cost-optimal level is described now both of the 4th data point of the curve “BWK+Sol” and the 5th data point of the curve “BWK+Sol” (cost-optimal range from 48-53 kWh/(m²a); the 4th data point has minimal lower global costs < 1 €/m²)). The additional costs of better energy performance standards stay nearly constant (EB 55) or are decreasing (EB 40, PH) compared to the basic scenario.

Low energy price development MFH: The cost-optimal level is described still by the 4th data point of the curve “BWK+Sol” (cost-optimal level 53 kWh/(m²a)). The additional costs of better energy performance standards stay nearly constant (EB 55) or are increasing (EB 40, PH) compared to the basic scenario.

Due to lower actual energy prices for wood pellets and relatively high energy use for heating and hot water, the effect of a low (high) energy price development on the additional costs is less obvious for the variants with wood pellet boiler in the MFH (EB 55 and 40). In the case of EB 55 the net present value of energy costs is even decreasing (increasing) more than for the variant EnEV 09 (with gas condensing boiler and solar heating system).

Discount rate 1 % (real) and high energy price development

An additionally variation of input parameters was carried out exemplary for the SFH reference building for a high energy price development scenario and a low discount rate of 1 %. The results are shown in figure 8 (see also table 27 in Annex 4). The changes are obvious especially for the heat supply systems with condensing boiler. The cost-optimal primary energy demand moves to approx. 48 kWh/m²/a and the additional costs from EnEV 09 to nZEB level are decreasing e.g. for efficiency building 40 from 101 €/m² to 19 €/m² (see table 13).

Compared to the current minimum energy performance requirements of EnEV 2009 (intersection of the red vertical line with the curve "BWK+Sol") the energy performance standards efficiency building 55 (5. data point of the curve "BWK+Sol+WRG) and passive house (6th data point of the curve "BWK+WRG) could now be realised with nearly the same or in the case of PH even with lower global costs.

Fig. 8: Global costs SFH / all heat supply systems (high energy price development/discount rate 1 %)

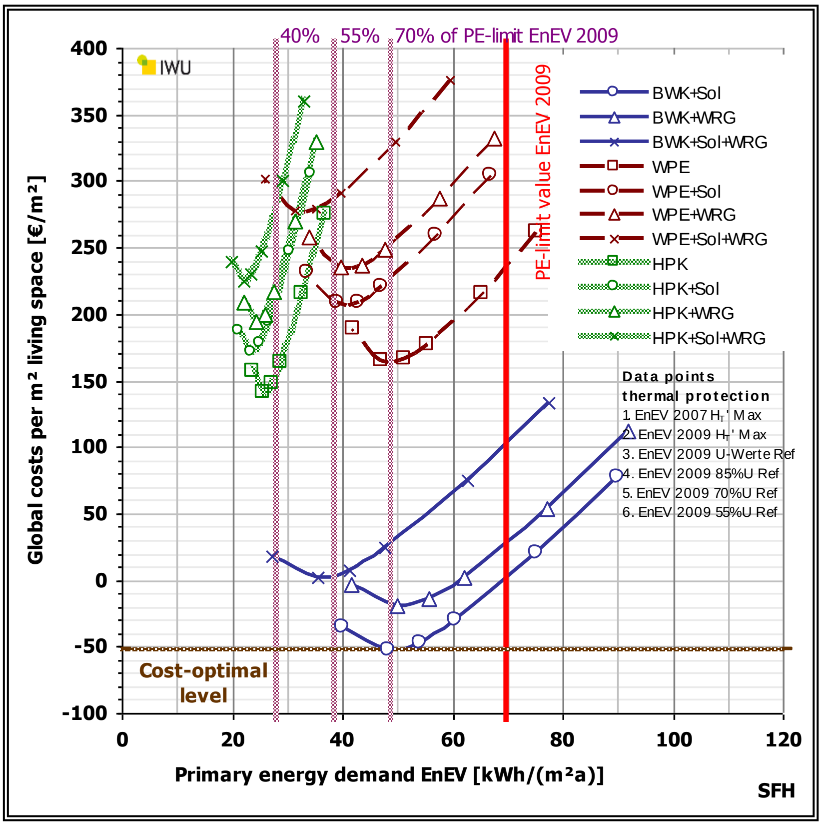


Table 13: Results of sensitivity analysis SFH (high energy price development; low discount rate)

ENERGY PRICE DEVELOPMENT / DISCOUNT RATE		4.3 % (REAL) / 1 %	2.8 % (REAL) / 3 % (BASIC SCENARIO)
Cost-optimal level	[kWh/m²a]	48	54
Gap to EnEV 09	[kWh/m²a] (%)	22 (31%)	16 (23%)
Additional costs CO to EnEV 09	[€/m²]	-52	-12
Additional costs PH to EnEV 09	[€/m²]	-3	+65
Additional costs EB 55 to EnEV 09	[€/m²]	+2	+58
Additional costs EB 40 to EnEV 09	[€/m²]	+19	+101

Disposal costs

Furthermore disposal costs are exemplarily considered for one reference building and thermal protection measures. The disposal costs at the end of the lifetime (50 years) are assumed to an overall percentage (30 %) of the initial investment costs. Discounted to the end of the calculation period the disposal costs are reducing the residual value of the insulation measures by about 17 %. As a result, the global costs are increasing marginal and the cost-optimum moves slight to the right. Due to discounting the influence of future disposal costs on the cost-optimal level remains marginal.

References

[BMVBS 2010] BMVBS (Hrsg.): Externe Kosten im Hochbau, BMVBS-Online-Publikation, Nr. 17/2010

[EC 2010] EU energy trends to 2030 – update 2009; European Commission; 2010

[EC 2012a] Commission Regulation (EU) No 244/2012 of 16 January 2012; supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings (recast) by establishing a comparative methodology framework for cost optimal levels of minimum energy performance requirements for buildings and building elements

[EC 2012b] Guidelines accompanying the document Commission Delegated Regulation No 244/2012 of 16 January 2012; supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings (recast) by establishing a comparative methodology framework for cost optimal levels of minimum energy performance requirements for buildings and building elements

[Hinz 2010] Hinz, E.: Untersuchung zur weiteren Verschärfung der energetischen Anforderungen an Wohngebäude mit der EnEV 2012. Teil 1 - Kosten energierelevanter Bau- und Anlagenteile in der energetischen Modernisierung von Altbauten; im Auftrag des BBSR; IWU; Darmstadt 2010

[IWU 2012] Diefenbach, N., Enseling, A., Hinz, E., Loga, T.: Evaluierung und Fortentwicklung der EnEV 2009: Untersuchung zu ökonomischen Rahmenbedingungen im Wohnungsbau; im Auftrag des BBSR; IWU / BBSR 2012

[ZUB 2010] Klauß, Swen; Maas, Anton: Entwicklung einer Datenbank mit Modellgebäuden für energiebezogene Untersuchungen, insbesondere der Wirtschaftlichkeit; Studie durchgeführt im Auftrag des BMVBS sowie des BBSR; Zentrum für Umweltbewusstes Bauen e.V., Kassel 2010

Annex 1: Initial investment costs

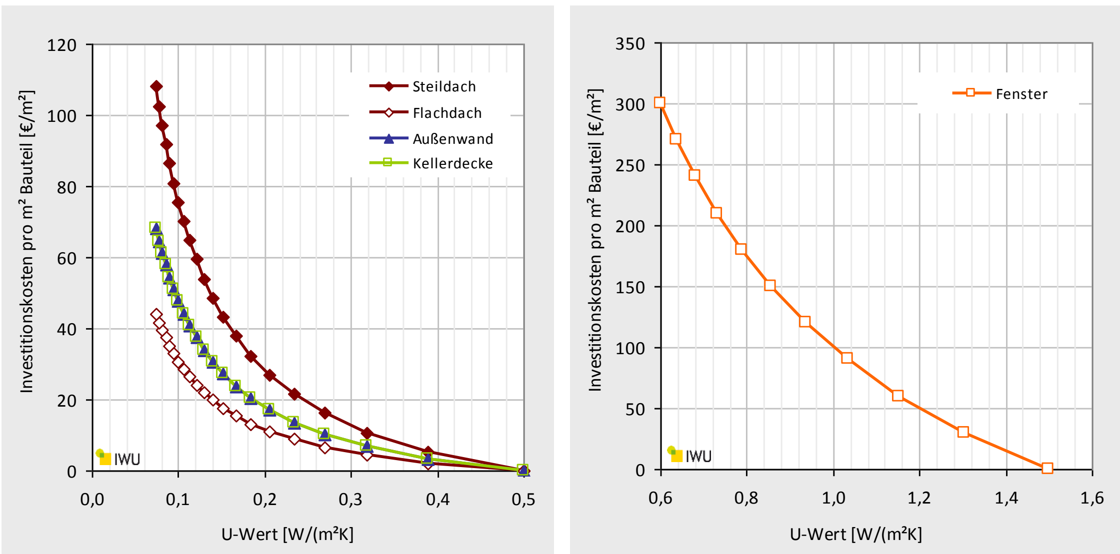
The following table shows the used parameters of the cost functions (additional costs) for thermal protection measures on building elements.

Table 14: Parameters of the cost functions (additional costs) for thermal protection measures on building elements

	arithmetic averages		used approach (rounded)	
	specific costs thermal resistance	specific costs insulation	specific costs thermal resistance	specific costs insulation
	€/(m²K)	€/cm/m²	€/(m²K/W)	€/cm/m²
Flat roof	3,96	1,13		1,1
Steep roof	9,54	2,72		2,7
Outer wall	5,85	1,67		1,7
Cellar ceiling	5,88	1,68		1,7
Window		299	300	
Roof window		786	800	
External door		1057	1100	

Based on the shown parameters, the following dependences between initial investment costs and U-values of building components become obvious. Important are only the differences between two thermal protection standards – the zero-point is randomised.

Fig. 9: Initial investment costs as a function of u-values for building components



The following table shows the used difference costs for energy saving installations.

Table 15: Difference costs for technical installations

	SFH	MFH
Heat generator: cost difference compared to system with gas condensing boiler		
Woodpellet boiler	+ 80 €/m²	+ 31 €/m²
Electrical heat pump (heat source: ground)	+ 121 €/m²	+ 60 €/m²
Heat distribution and emission: cost difference compared to system with standard radiators		
Under floor heating	+ 20 €/m²	+ 25 €/m²
Additional costs of supplemental systems		
Thermal solar DHW system	+ 35 €/m²	+ 35 €/m²
Exhaust ventilation system, including supply air valves	+ 20 €/m²	+ 37 €/m²
Ventilation system with heat recovery (thermal efficiency 80%)	+ 64 €/m²	+ 110 €/m²
Costs savings due to reduced heating power (best standard compared to poorest standard)		
Heat generators		
Gas condensing boiler	- €	- €
Woodpellets boiler	- €	- €
Electrical heat pump (heat source: ground)	-5 €	-10 €
Heat emission system		
Standard radiators	-4 €	-4 €
Under floor heating	-6 €	-6 €

Annex 2: Reporting table for energy performance relevant data

Table 16: Reporting table for energy performance relevant data (Table 3 of [EC 2012b])

			Quantity		Unit
Building	Model building		SFH semi-detached	MFH semi-detached	
	Variant		requirements of EnEV 2009 and EEWärmeG; assuming condensing boilers + thermal solar systems		
Calculation	Method and tool(s)		EnEV 2009 / DIN V 4108-6 + DIN V 4701-10 calculation tool: EnEV-XL 4.0		
	Primary energy conversion factors		natural gas: 1.1 electricity: 2.6 wood pellets: 0.2		
Climate condition	Location		reference climate Germany (synthetical climate)		
	Heating degree-days		according to DIN V 4108-6 (base temperature 10°C): (10 °C - 3.3°C) · 185 d/a = 1240 Kd/a according to TABULA (base temperature 12°C, see www.building-typology.eu): (12 °C - 4.4°C) · 222 d/a = 1687 Kd/a		
	Source of climatic dataset		reference climate Germany, according to DIN V 4108-6 Part D		
Reference area	Living space according to national housing regulations		139.0	473.0	m²
	Reference area according to national asset rating method		187.5	591.4	m²
Building geometry	Length x Width x Height		external dimensions: 7.5 x 11.4 x 9.7 (internal dimensions cannot be determined due to lack of plans)	external dimensions: 11.0 x 14.0 x 12.0 (internal dimensions cannot be determined due to lack of plans)	m x m x m
	Number of floors		1 complete storey + attic storey	4 complete storeys	
	Surface to volume ratio		0.59 (based on external dimensions)	0.42 (based on external dimensions)	m²/m³
	Ratio of window area over total building envelope	South	3.3%	0.0%	
		East	2.5%	7.0%	
		North	1.7%	0.0%	
		West	0.0%	8.5%	
	Orientation		0°	0°	
Internal gains	Building utilisation		residential	residential	W/m²
	Average thermal gain		sum of all sources: 5	sum of all sources: 5	W/m²

Building elements	Average U-value of walls		0.33	0.29	W/(m²K)
	Average U-value of roof		0.31	0.26	W/(m²K)
	Average U-value of basement		0.48	0.43	W/(m²K)
	Average U-value of windows		1.30	1.30	W/(m²K)
	Thermal bridges	additional losses related to the thermal envelope area	0.02 (based on external dimensions)	0.02 (based on external dimensions)	W/(m²K)
	Infiltration rate (air changes per hour)	blower door: 50 Pa	3.0 (requirement for buildings without ventilation system)	3.0 (requirement for buildings without ventilation system)	1/h
Building systems	Efficiencies of heating systems (related to net calorific value)	generation	104.2%	102.2%	
		distribution	2.1%	2.4%	
		emission + control	1.4%	2.0%	
	Efficiencies of DHW systems (related to net calorific value)	generation	89.1%	91.2%	
		storage	12.6%	11.0%	
		distribution	23.1%	40.3%	
Building energy need / use (related to living space)	Energy need	heating	78	56	kWh/(m²a)
		DHW	17	16	kWh/(m²a)
	Energy use for auxiliary systems		5	3	kWh/(m²a)
	Thermal energy from RES (thermal solar collector)		16	14	kWh/(m²a)
	Delivered energy for heating and DHW	electricity	0	0	kWh/(m²a)
		fossil fuel (natural gas)	74	43	kWh/(m²a)
		biomass (wood pellets)	0	0	kWh/(m²a)
Environ-mental assessment	Primary energy		94	59	kWh/(m²a)

Annex 3: Global cost calculation – output data

In the following, the global costs calculation from the private financial and the macroeconomic perspective is documented with regard to table 6 of Annex III of the C-O regulation. The documented initial investment costs for thermal protection and technical installations are calculated as difference costs referring to a given basis (see Annex 1) and are including replacement costs for technical installations. For the sake of clarity, only the most important variants are presented for both reference buildings. The most cost-effective variants towards nZEB levels are highlighted in grey. The additional costs of these standards compared to EnEV 09 are resulting as differences from the global cost calculated for the nZEB variants and the global cost calculated for EnEV 09.

Table 17: Output data and global cost calculation SFH (selected variants; private financial perspective)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost	Calculation period:	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
		maintenance cost [€/m²a] / [€/m²] (NPV)	30 years Energy costs by fuel medium energy price scenario [€/m²] (NPV)				
EnEV 09 (BWK+Sol)	75,65	0,67 13,12	186,35	3,43	3%	Insulation: 50 Windows: 30 Installations: 15	271,69
Cost optimum (4/BWK+Sol)	109,59	0,64 12,63	147,02	9,36	3%	Insulation: 50 Windows: 30 Installations: 15	259,88
EB 55 (5/BWK+Sol+WRG)	211,22	1,51 29,68	103,55	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	330,07
PH (6/BWK+WRG)	229,77	0,80 15,69	117,92	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	336,29
EB 40 (6/BWK+Sol+WRG)	287,17	1,50 29,41	82,79	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	372,29
EB 55 (5/HPK)	212,86	1,53 30,07	181,81	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	410,36
EB 40 (6/HPK)	288,81	1,52 29,80	160,82	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	452,35
PH (6/HPK+WRG)	360,97	2,40 47,06	130,83	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	511,77
EB 55 (5/WPE+Sol)	330,69	2,97 58,25	122,64	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	497,21
PH (6/WPE+WRG)	420,01	3,12 61,18	110,16	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	564,26
EB 40 (6/WPE+Sol+WRG)	477,41	3,82 74,90	87,18	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	612,41

Table 18: Output data and global cost calculation MFH (selected variants; private financial perspective)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	70,95	0,66 / 12,97	150,53	2,76	3%	Insulation: 50 Windows: 30 Installations: 15	231,69
Cost optimum (4/BWK+Sol)	84,59	0,00 / 12,64	132,08	5,23	3%	Insulation: 50 Windows: 30 Installations: 15	224,08
EB 55 (5/BWK+Sol+WRG)	224,22	2,09 / 41,02	90,50	8,69	3%	Insulation: 50 Windows: 30 Installations: 15	347,04
PH (6/BWK+WRG)	260,57	2,08 / 40,78	77,71	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	364,21
EB 40 (6/HPK+Sol)	191,69	1,24 / 24,31	116,97	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	318,12
EB 55 (5/HPK)	97,94	0,55 / 10,82	154,74	8,69	3%	Insulation: 50 Windows: 30 Installations: 15	254,80
EB 40 (6/HPK)	134,29	0,54 / 10,59	142,21	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	272,24
PH (6/HPK+WRG)	254,01	2,00 / 39,22	115,11	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	393,48
EB 55 (6/WPE+Sol)	222,85	1,62 / 31,76	93,04	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	332,80
PH (6/WPE+WRG)	285,17	2,38 / 46,67	94,72	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	411,71
EB 40 (6/WPE+Sol+WRG)	342,57	3,08 / 60,39	74,83	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	462,94

Table 19: Output data and global cost calculation SFH (selected variants; macroeconomic perspective)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Cost of green house gas emissions [€/m²]	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	63,57	0,56 11,02	156,60	2,88	12,97	3%	Insulation: 50 Windows: 30 Installations: 15	241,29
Cost optimum (4/BWK+Sol)	92,10	0,54 10,62	123,54	7,87	10,09	3%	Insulation: 50 Windows: 30 Installations: 15	228,48
EB 55 (5/BWK+Sol+WRG)	177,49	1,27 24,94	87,01	12,08	6,71	3%	Insulation: 50 Windows: 30 Installations: 15	284,08
PH (6/BWK+WRG)	193,08	0,67 13,18	99,10	22,76	7,83	3%	Insulation: 50 Windows: 30 Installations: 15	290,43
EB 40 (6/BWK+Sol+WRG)	241,32	1,26 24,72	69,58	22,76	5,19	3%	Insulation: 50 Windows: 30 Installations: 15	318,03
EB 55 (5/HPK)	178,87	1,29 25,27	152,78	12,08	4,74	3%	Insulation: 50 Windows: 30 Installations: 15	349,59
EB 40 (6/HPK)	242,70	1,28 25,05	135,14	22,76	4,38	3%	Insulation: 50 Windows: 30 Installations: 15	384,51
PH (6/HPK+WRG)	303,34	2,02 39,55	109,94	22,76	4,22	3%	Insulation: 50 Windows: 30 Installations: 15	434,28
EB 55 (5/WPE+Sol)	277,89	2,50 48,95	103,06	12,08	7,87	3%	Insulation: 50 Windows: 30 Installations: 15	425,69
PH (6/WPE+WRG)	352,95	2,62 51,41	92,58	22,76	6,87	3%	Insulation: 50 Windows: 30 Installations: 15	481,04
EB 40 (6/WPE+Sol+WRG)	401,18	3,21 62,94	73,26	22,76	5,22	3%	Insulation: 50 Windows: 30 Installations: 15	519,85

Table 20: Output data and global cost calculation MFH (selected variants; macroeconomic perspective)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Cost of green house gas emissions [€/m²]	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	59,62	0,56 10,90	126,50	2,32	10,55	3%	Insulation: 50 Windows: 30 Installations: 15	205,25
Cost optimum (4/BWK+Sol)	71,08	0,54 10,62	110,99	4,40	9,20	3%	Insulation: 50 Windows: 30 Installations: 15	197,51
EB 55 (5/BWK+Sol+WRG)	188,42	1,76 34,47	76,05	7,31	5,97	3%	Insulation: 50 Windows: 30 Installations: 15	297,61
PH (6/BWK+WRG)	170,73	1,16 22,74	89,47	12,48	7,17	3%	Insulation: 50 Windows: 30 Installations: 15	277,63
EB 40 (6/HPK+Sol)	161,08	1,04 20,43	98,30	12,48	3,35	3%	Insulation: 50 Windows: 30 Installations: 15	270,68
EB 55 (5/HPK)	82,30	0,46 9,09	130,03	7,31	3,94	3%	Insulation: 50 Windows: 30 Installations: 15	218,05
EB 40 (6/HPK)	112,85	0,45 8,90	119,51	12,48	3,72	3%	Insulation: 50 Windows: 30 Installations: 15	232,49
PH (6/HPK+WRG)	213,45	1,68 32,95	96,73	12,48	3,58	3%	Insulation: 50 Windows: 30 Installations: 15	334,24
EB 55 (6/WPE+Sol)	187,27	1,36 26,69	78,19	12,48	5,99	3%	Insulation: 50 Windows: 30 Installations: 15	285,65
PH (6/WPE+WRG)	239,64	2,00 39,22	79,60	12,48	5,96	3%	Insulation: 50 Windows: 30 Installations: 15	351,93
EB 40 (6/WPE+Sol+WRG)	287,87	2,59 50,75	62,89	12,48	4,56	3%	Insulation: 50 Windows: 30 Installations: 15	393,58

Annex 4: Sensitivity analysis – output data

Energy price development

Fig. 10: Global costs SFH / MFH all heat supply systems (high energy price development)

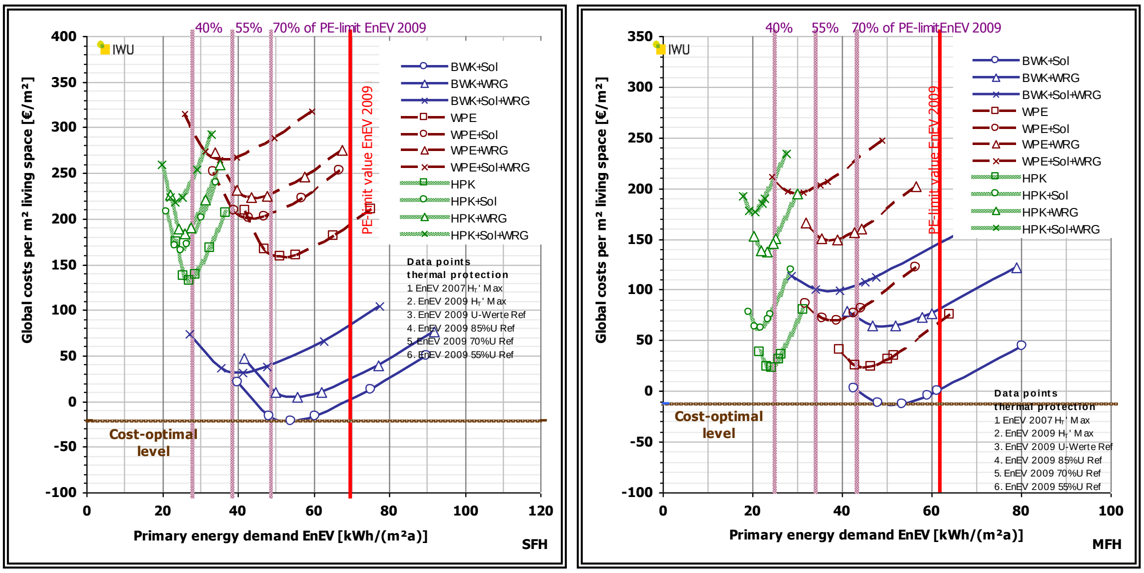


Fig. 11: Global costs SFH / MFH all heat supply systems (low energy price development)

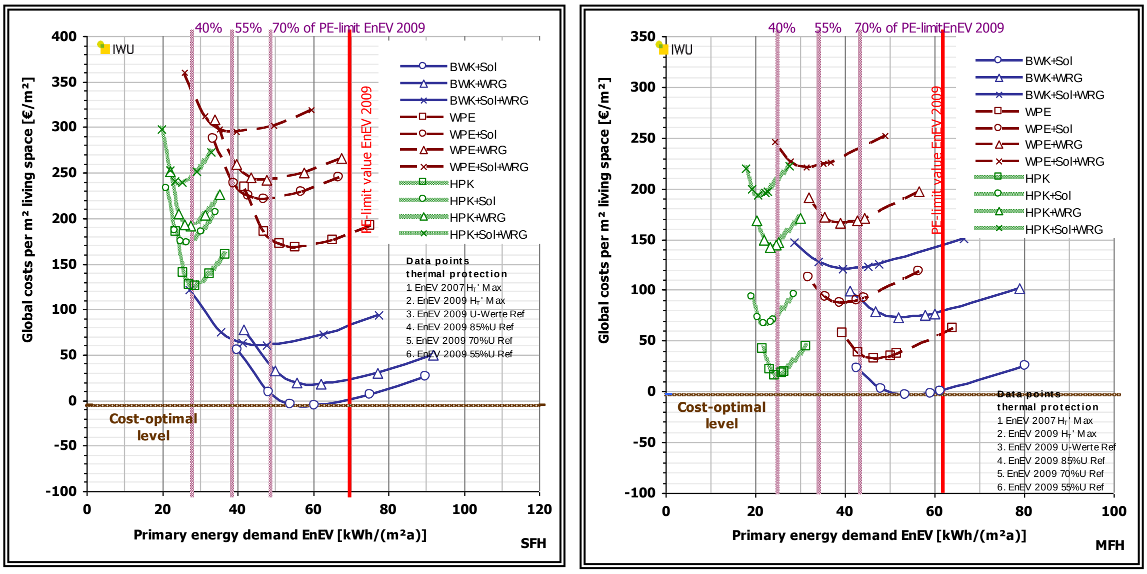


Table 21: Output data and global cost calculation SFH (selected variants; private financial perspective; high energy price development)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	75,65	0,67 13,12	233,88	3,43	3%	Insulation: 50 Windows: 30 Installations: 15	319,22
Cost optimum (4/BWK+Sol)	109,59	0,64 12,63	184,51	9,36	3%	Insulation: 50 Windows: 30 Installations: 15	297,38
EB 55 (5/BWK+Sol+WRG)	211,22	1,51 29,68	129,96	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	356,48
PH (6/BWK+WRG)	229,77	0,80 15,69	148,00	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	366,37
EB 40 (6/BWK+Sol+WRG)	287,17	1,50 29,41	103,91	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	393,40
EB 55 (5/HPK)	212,86	1,53 30,07	228,17	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	456,73
EB 40 (6/HPK)	288,81	1,52 29,80	201,84	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	493,36
PH (6/HPK+WRG)	360,97	2,40 47,06	164,20	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	545,14
EB 55 (5/WPE+Sol)	330,69	2,97 58,25	153,91	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	528,48
PH (6/WPE+WRG)	420,01	3,12 61,18	138,26	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	592,36
EB 40 (6/WPE+Sol+WRG)	477,41	3,82 74,90	109,42	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	634,64

Table 22: Output data and global cost calculation MFH (selected variants; private financial perspective; high energy price development)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost: maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years — Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	70,95	0,66 / 12,97	188,92	2,76	3%	Insulation: 50 Windows: 30 Installations: 15	270,08
Cost optimum (4/BWK+Sol)	84,59	0,00 / 12,64	165,77	5,23	3%	Insulation: 50 Windows: 30 Installations: 15	257,76
EB 55 (5/BWK+Sol+WRG)	224,22	2,09 / 41,02	113,59	8,69	3%	Insulation: 50 Windows: 30 Installations: 15	370,12
PH (6/BWK+WRG)	260,57	2,08 / 40,78	97,53	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	384,03
EB 40 (6/HPK+Sol)	191,69	1,24 / 24,31	146,81	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	347,96
EB 55 (5/HPK)	97,94	0,55 / 10,82	194,20	8,69	3%	Insulation: 50 Windows: 30 Installations: 15	294,26
EB 40 (6/HPK)	134,29	0,54 / 10,59	178,48	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	308,51
PH (6/HPK+WRG)	254,01	2,00 / 39,22	144,46	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	422,84
EB 55 (6/WPE+Sol)	222,85	1,62 / 31,76	116,77	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	356,53
PH (6/WPE+WRG)	285,17	2,38 / 46,67	118,88	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	435,86
EB 40 (6/WPE+Sol+WRG)	342,57	3,08 / 60,39	93,92	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	482,03

Table 23: Output data and global cost calculation SFH (selected variants; private financial perspective; low energy price development)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost / maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years / Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	75,65	0,67 13,12	148,83	3,43	3%	Insulation: 50 Windows: 30 Installations: 15	228,67
Cost optimum (3/BWK+Sol)	91,92	0,65 12,83	130,23	6,31	3%	Insulation: 50 Windows: 30 Installations: 15	230,28
EB 55 (5/BWK+Sol+WRG)	211,22	1,51 29,68	82,70	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	309,22
PH (6/BWK+WRG)	229,77	0,80 15,69	94,18	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	312,55
EB 40 (6/BWK+Sol+WRG)	287,17	1,50 29,41	66,12	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	355,62
EB 55 (5/HPK)	212,86	1,53 30,07	145,20	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	373,76
EB 40 (6/HPK)	288,81	1,52 29,80	128,44	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	419,97
PH (6/HPK+WRG)	360,97	2,40 47,06	104,49	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	485,43
EB 55 (5/WPE+Sol)	330,69	2,97 58,25	97,95	14,37	3%	Insulation: 50 Windows: 30 Installations: 15	472,51
PH (6/WPE+WRG)	420,01	3,12 61,18	87,98	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	542,08
EB 40 (6/WPE+Sol+WRG)	477,41	3,82 74,90	69,63	27,09	3%	Insulation: 50 Windows: 30 Installations: 15	594,85

Table 24: Output data and global cost calculation MFH (selected variants; private financial perspective; low energy price development)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost / maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years / Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	70,95	0,66 / 12,97	120,22	2,76	3%	Insulation: 50 Windows: 30 Installations: 15	201,38
Cost optimum (4/BWK+Sol)	84,59	0,00 / 12,64	105,49	5,23	3%	Insulation: 50 Windows: 30 Installations: 15	197,49
EB 55 (5/BWK+Sol+WRG)	224,22	2,09 / 41,02	72,28	8,69	3%	Insulation: 50 Windows: 30 Installations: 15	328,82
PH (6/BWK+WRG)	260,57	2,08 / 40,78	62,06	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	348,56
EB 40 (6/HPK+Sol)	191,69	1,24 / 24,31	93,42	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	294,57
EB 55 (5/HPK)	97,94	0,55 / 10,82	123,58	8,69	3%	Insulation: 50 Windows: 30 Installations: 15	223,64
EB 40 (6/HPK)	134,29	0,54 / 10,59	113,58	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	243,60
PH (6/HPK+WRG)	254,01	2,00 / 39,22	91,93	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	370,30
EB 55 (6/WPE+Sol)	222,85	1,62 / 31,76	74,31	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	314,07
PH (6/WPE+WRG)	285,17	2,38 / 46,67	75,65	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	392,63
EB 40 (6/WPE+Sol+WRG)	342,57	3,08 / 60,39	59,77	14,85	3%	Insulation: 50 Windows: 30 Installations: 15	447,88

Discount rate

Fig. 12: Global costs SFH / MFH all heat supply systems (discount rate 1 %)

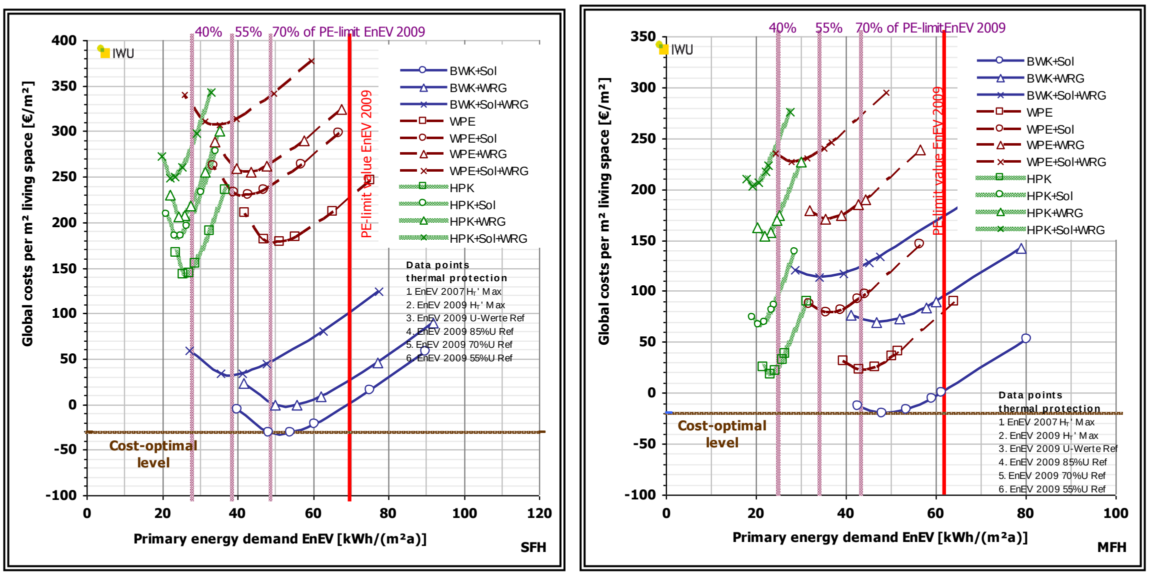


Table 25: Output data and global cost calculation SFH (selected variants; private financial perspective; discount rate 1%)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	83,01	0,67 17,16	253,51	6,17	3%	Insulation: 50 Windows: 30 Installations: 15	347,50
Cost optimum (4/BWK+Sol)	116,68	0,64 16,52	200,00	16,84	3%	Insulation: 50 Windows: 30 Installations: 15	316,35
EB 55 (5/BWK+Sol+WRG)	227,87	1,51 38,81	140,86	25,85	3%	Insulation: 50 Windows: 30 Installations: 15	381,69
PH (6/BWK+WRG)	238,57	0,80 20,51	160,42	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	370,78
EB 40 (6/BWK+Sol+WRG)	303,67	1,50 38,46	112,63	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	406,03
EB 55 (5/HPK)	229,73	1,53 39,32	247,32	25,85	3%	Insulation: 50 Windows: 30 Installations: 15	490,52
EB 40 (6/HPK)	305,53	1,52 38,97	218,77	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	514,55
PH (6/HPK+WRG)	387,37	2,40 61,54	177,98	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	578,16
EB 55 (5/WPE+Sol)	363,37	2,97 76,17	166,83	25,85	3%	Insulation: 50 Windows: 30 Installations: 15	580,52
PH (6/WPE+WRG)	454,33	3,12 80,00	149,86	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	635,47
EB 40 (6/WPE+Sol+WRG)	519,43	3,82 97,95	118,60	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	687,25

Table 26: Output data and global cost calculation MFH (selected variants; private financial perspective; discount rate 1%)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost / maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years / Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	78,22	0,66 / 16,96	204,77	4,96	3%	Insulation: 50 Windows: 30 Installations: 15	295,00
Cost optimum (5/BWK+Sol)	111,45	0,63 / 16,20	163,00	15,64	3%	Insulation: 50 Windows: 30 Installations: 15	275,00
EB 55 (5/BWK+Sol+WRG)	247,23	2,09 / 53,64	123,12	15,64	3%	Insulation: 50 Windows: 30 Installations: 15	408,34
PH (6/BWK+WRG)	283,45	2,08 / 53,33	105,71	26,71	3%	Insulation: 50 Windows: 30 Installations: 15	415,78
EB 40 (6/HPK+Sol)	205,33	1,24 / 31,79	159,13	26,71	3%	Insulation: 50 Windows: 30 Installations: 15	369,53
EB 55 (5/HPK)	104,01	0,55 / 14,15	210,49	15,64	3%	Insulation: 50 Windows: 30 Installations: 15	313,01
EB 40 (6/HPK)	140,23	0,54 / 13,85	193,46	26,71	3%	Insulation: 50 Windows: 30 Installations: 15	320,82
PH (6/HPK+WRG)	276,01	2,00 / 51,28	156,59	26,71	3%	Insulation: 50 Windows: 30 Installations: 15	457,16
EB 55 (6/WPE+Sol)	240,67	1,62 / 41,54	126,57	26,71	3%	Insulation: 50 Windows: 30 Installations: 15	382,06
PH (6/WPE+WRG)	311,35	2,38 / 61,03	128,86	26,71	3%	Insulation: 50 Windows: 30 Installations: 15	474,52
EB 40 (6/WPE+Sol+WRG)	376,45	3,08 / 78,97	101,80	26,71	3%	Insulation: 50 Windows: 30 Installations: 15	530,51

Table 27: Output data and global cost calculation SFH (selected variants; private financial perspective; discount rate 1% and high energy price development)

Variant	Initial investment cost (including NPV replacement cost) [€/m²]	Annual running cost / maintenance cost [€/m²a] / [€/m²] (NPV)	Calculation period: 30 years / Energy costs by fuel medium energy price scenario [€/m²] (NPV)	Residual value [€/m²] (NPV)	Discount rate [%]	Estimated economic lifetime [a]	Global cost calculated [€/m²]
EnEV 09 (BWK+Sol)	83,01	0,67 17,16	325,47	6,17	3%	Insulation: 50 Windows: 30 Installations: 15	419,47
Cost optimum (5/BWK+Sol)	146,03	0,63 16,25	231,13	25,85	3%	Insulation: 50 Windows: 30 Installations: 15	367,55
EB 55 (5/BWK+Sol+WRG)	227,87	1,51 38,81	180,85	25,85	3%	Insulation: 50 Windows: 30 Installations: 15	421,67
PH (6/BWK+WRG)	238,57	0,80 20,51	205,96	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	416,31
EB 40 (6/BWK+Sol+WRG)	303,67	1,50 38,46	144,60	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	438,01
EB 55 (5/HPK)	229,73	1,53 39,32	317,53	25,85	3%	Insulation: 50 Windows: 30 Installations: 15	560,73
EB 40 (6/HPK)	305,53	1,52 38,97	280,88	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	576,66
PH (6/HPK+WRG)	387,37	2,40 61,54	228,50	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	628,68
EB 55 (5/WPE+Sol)	363,37	2,97 76,17	214,19	25,85	3%	Insulation: 50 Windows: 30 Installations: 15	627,88
PH (6/WPE+WRG)	454,33	3,12 80,00	192,40	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	678,01
EB 40 (6/WPE+Sol+WRG)	519,43	3,82 97,95	152,27	48,73	3%	Insulation: 50 Windows: 30 Installations: 15	720,92

Annex 5: Energy performance – output data

Reference building SFH

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		BWK	BWK	BWK	BWK	BWK	BWK	BWK+Sol	BWK+Sol	BWK+Sol	BWK+Sol	BWK+Sol	BWK+Sol
reference area	m²	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52
energy need for heating	kWh/(m²a)	68,72	54,68	40,64	34,58	29,04	21,31	68,72	54,68	40,64	34,58	29,04	21,31
energy use for heating and DHH													
gas	kWh/(m²a)	87,62	74,15	60,67	54,85	49,53	42,11	73,71	60,23	46,75	40,94	35,62	28,19
wood pellets	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity	kWh/(m²a)	3,12	3,12	3,12	3,12	3,12	3,12	3,46	3,46	3,46	3,46	3,46	3,46
CO2-emissions	kg/(m²a)	23,36	20,07	16,78	15,36	14,06	12,25	20,17	16,89	13,60	12,18	10,88	9,07
primary energy demand	kWh/(m²a)	104,51	89,68	74,85	68,46	62,60	54,44	90,07	75,24	60,42	54,02	48,17	40,00
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	34,80	19,97	5,15	-1,25	-7,10	-15,27	20,37	5,54	-9,29	-15,68	-21,54	-29,70

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		BWK+WRG	BWK+WRG	BWK+WRG	BWK+WRG	BWK+WRG	BWK+WRG	BWK+Sol+WRG	BWK+Sol+WRG	BWK+Sol+WRG	BWK+Sol+WRG	BWK+Sol+WRG	BWK+Sol+WRG
reference area	m²	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52
energy need for heating	kWh/(m²a)	71,57	57,47	43,35	37,24	31,66	23,83	71,57	57,47	43,35	37,24	31,66	23,83
energy use for heating and DHH													
gas	kWh/(m²a)	73,85	60,32	46,76	40,90	35,54	28,02	59,92	46,39	32,83	26,97	21,61	14,09
wood pellets	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity	kWh/(m²a)	4,12	4,12	4,12	4,12	4,12	4,12	4,46	4,46	4,46	4,46	4,46	4,46
CO2-emissions	kg/(m²a)	20,63	17,33	14,02	12,59	11,28	9,45	17,44	14,14	10,83	9,40	8,09	6,26
primary energy demand	kWh/(m²a)	91,95	77,07	62,16	55,71	49,81	41,54	77,50	62,62	47,70	41,25	35,36	27,09
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	22,25	7,36	-7,55	-14,00	-19,89	-28,17	7,80	-7,09	-22,00	-28,45	-34,34	-42,62

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		WPE	WPE	WPE	WPE	WPE	WPE	WPE+Sol	WPE+Sol	WPE+Sol	WPE+Sol	WPE+Sol	WPE+Sol
reference area	m²	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52
energy need for heating	kWh/(m²a)	68,72	54,68	40,64	34,58	29,04	21,31	68,72	54,68	40,64	34,58	29,04	21,31
energy use for heating and DHH													
gas	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood pellets	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity	kWh/(m²a)	28,87	25,08	21,29	19,65	18,15	16,07	25,71	21,92	18,13	16,50	15,00	12,91
CO2-emissions	kg/(m²a)	18,27	15,87	13,47	12,44	11,49	10,17	16,28	13,88	11,48	10,44	9,50	8,17
primary energy demand	kWh/(m²a)	75,06	65,20	55,34	51,09	47,20	41,77	66,86	57,00	47,14	42,89	39,00	33,57
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	5,35	-4,51	-14,36	-18,61	-22,51	-27,93	-2,85	-12,71	-22,56	-26,81	-30,70	-36,13

Table 28: Energy performance calculation output data – SFH

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		WPE+WRG	WPE+WRG	WPE+WRG	WPE+WRG	WPE+WRG	WPE+WRG	WPE+Sol+WRG	WPE+Sol+WRG	WPE+Sol+WRG	WPE+Sol+WRG	WPE+Sol+WRG	WPE+Sol+WRG
reference area	m²	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52
energy need for heating	kWh/(m²a)	71,57	57,47	43,35	37,24	31,66	23,83	71,57	57,47	43,35	37,24	31,66	23,83
energy use for heating and DHH													
gas	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood pellets	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity	kWh/(m²a)	25,99	22,19	18,37	16,73	15,22	13,10	22,84	19,03	15,22	13,57	12,07	9,95
CO2-emissions	kg/(m²a)	16,45	14,04	11,63	10,59	9,63	8,29	14,46	12,05	9,64	8,59	7,64	6,30
primary energy demand	kWh/(m²a)	67,58	57,69	47,77	43,49	39,57	34,07	59,38	49,49	39,58	35,29	31,37	25,87
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	-2,12	-12,02	-21,93	-26,22	-30,14	-35,64	-10,32	-20,22	-30,13	-34,42	-38,33	-43,84

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		HPK	HPK	HPK	HPK	HPK	HPK	HPK+Sol	HPK+Sol	HPK+Sol	HPK+Sol	HPK+Sol	HPK+Sol
reference area	m²	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52
energy need for heating	kWh/(m²a)	68,72	54,68	40,64	34,58	29,04	21,31	68,72	54,68	40,64	34,58	29,04	21,31
energy use for heating and DHH													
gas	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood pellets	kWh/(m²a)	124,20	104,86	85,52	77,18	69,54	58,89	106,75	87,41	68,07	59,73	52,09	41,44
electricity	kWh/(m²a)	4,54	4,54	4,54	4,54	4,54	4,54	4,98	4,98	4,98	4,98	4,98	4,98
CO2-emissions	kg/(m²a)	7,97	7,17	6,38	6,04	5,73	5,29	7,53	6,74	5,95	5,60	5,29	4,85
primary energy demand	kWh/(m²a)	36,65	32,78	28,91	27,25	25,72	23,59	34,31	30,44	26,57	24,91	23,38	21,25
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	-33,05	-36,92	-40,79	-42,46	-43,99	-46,12	-35,39	-39,26	-43,13	-44,80	-46,33	-48,46

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		HPK+WRG	HPK+WRG	HPK+WRG	HPK+WRG	HPK+WRG	HPK+WRG	HPK+Sol+WRG	HPK+Sol+WRG	HPK+Sol+WRG	HPK+Sol+WRG	HPK+Sol+WRG	HPK+Sol+WRG
reference area	m²	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52	187,52
energy need for heating	kWh/(m²a)	71,57	57,47	43,35	37,24	31,66	23,83	71,57	57,47	43,35	37,24	31,66	23,83
energy use for heating and DHH													
gas	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood pellets	kWh/(m²a)	104,44	85,02	65,57	57,16	49,47	38,68	86,99	67,57	48,12	39,70	32,02	21,22
electricity	kWh/(m²a)	5,54	5,54	5,54	5,54	5,54	5,54	5,98	5,98	5,98	5,98	5,98	5,98
CO2-emissions	kg/(m²a)	7,79	6,99	6,20	5,85	5,54	5,09	7,35	6,56	5,76	5,42	5,10	4,66
primary energy demand	kWh/(m²a)	35,30	31,41	27,52	25,84	24,30	22,15	32,96	29,07	25,18	23,50	21,96	19,81
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	-34,41	-38,29	-42,18	-43,86	-45,40	-47,56	-36,75	-40,63	-44,52	-46,20	-47,74	-49,90

Reference building MFH

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		BWK	BWK	BWK	BWK	BWK	BWK	BWK+Sol	BWK+Sol	BWK+Sol	BWK+Sol	BWK+Sol	BWK+Sol
reference area	m²	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36
energy need for heating	kWh/(m²a)	56,63	39,26	37,06	31,78	26,89	21,85	56,63	39,26	37,06	31,78	26,89	21,85
energy use for heating and DHH													
gas	kWh/(m²a)	77,66	60,63	58,48	53,30	48,51	43,56	66,75	49,73	47,58	42,40	37,60	32,66
wood pellets	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity	kWh/(m²a)	2,46	2,46	2,46	2,46	2,46	2,46	2,59	2,59	2,59	2,59	2,59	2,59
CO2-emissions	kg/(m²a)	20,51	16,36	15,83	14,57	13,40	12,19	17,93	13,78	13,25	11,99	10,82	9,61
primary energy demand	kWh/(m²a)	91,83	73,11	70,74	65,04	59,77	54,33	80,17	61,44	59,07	53,38	48,10	42,67
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	30,55	11,82	9,45	3,76	-1,52	-6,95	18,89	0,16	-2,21	-7,90	-13,18	-18,61

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		BWK+WRG	BWK+WRG	BWK+WRG	BWK+WRG	BWK+WRG	BWK+WRG	BWK+Sol+WRG	BWK+Sol+WRG	BWK+Sol+WRG	BWK+Sol+WRG	BWK+Sol+WRG	BWK+Sol+WRG
reference area	m²	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36
energy need for heating	kWh/(m²a)	59,47	42,01	39,80	34,48	29,56	24,46	59,47	42,01	39,80	34,48	29,56	24,46
energy use for heating and DHH													
gas	kWh/(m²a)	63,58	46,47	44,30	39,09	34,27	29,27	51,88	34,77	32,60	27,39	22,57	17,56
wood pellets	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity	kWh/(m²a)	3,46	3,46	3,46	3,46	3,46	3,46	3,59	3,59	3,59	3,59	3,59	3,59
CO2-emissions	kg/(m²a)	17,71	13,53	13,00	11,73	10,56	9,33	14,93	10,76	10,23	8,96	7,78	6,56
primary energy demand	kWh/(m²a)	78,95	60,13	57,74	52,01	46,71	41,20	66,41	47,58	45,20	39,47	34,16	28,66
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	17,67	-1,16	-3,54	-9,27	-14,58	-20,08	5,12	-13,70	-16,08	-21,81	-27,12	-32,62

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		WPE	WPE	WPE	WPE	WPE	WPE	WPE+Sol	WPE+Sol	WPE+Sol	WPE+Sol	WPE+Sol	WPE+Sol
reference area	m²	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36
energy need for heating	kWh/(m²a)	56,63	39,26	37,06	31,78	26,89	21,85	56,63	39,26	37,06	31,78	26,89	21,85
energy use for heating and DHH													
gas	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood pellets	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity	kWh/(m²a)	24,59	19,90	19,31	17,88	16,56	15,20	21,71	17,02	16,42	15,00	13,68	12,31
CO2-emissions	kg/(m²a)	15,57	12,60	12,22	11,32	10,48	9,62	13,74	10,77	10,40	9,49	8,66	7,80
primary energy demand	kWh/(m²a)	63,93	51,74	50,20	46,49	43,05	39,51	56,44	44,25	42,70	38,99	35,56	32,02
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	2,65	-9,54	-11,09	-14,79	-18,23	-21,77	-4,84	-17,04	-18,58	-22,29	-25,72	-29,26

Table 29: Energy performance calculation output data - MFH

thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		WPE+WRG	WPE+WRG	WPE+WRG	WPE+WRG	WPE+WRG	WPE+WRG	WPE+Sol+WRG	WPE+Sol+WRG	WPE+Sol+WRG	WPE+Sol+WRG	WPE+Sol+WRG	WPE+Sol+WRG
reference area	m²	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36
energy need for heating	kWh/(m²a)	59,47	42,01	39,80	34,48	29,56	24,46	59,47	42,01	39,80	34,48	29,56	24,46
energy use for heating and DHH													
gas	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood pellets	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
electricity	kWh/(m²a)	21,71	17,00	16,40	14,97	13,64	12,26	18,83	14,12	13,52	12,08	10,75	9,38
CO2-emissions	kg/(m²a)	13,74	10,76	10,38	9,47	8,63	7,76	11,92	8,94	8,56	7,65	6,81	5,93
primary energy demand	kWh/(m²a)	56,45	44,19	42,64	38,91	35,46	31,87	48,96	36,70	35,15	31,42	27,96	24,38
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	-4,83	-17,09	-18,64	-22,37	-25,83	-29,41	-12,32	-24,58	-26,13	-29,87	-33,32	-36,90
thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		HPK	HPK	HPK	HPK	HPK	HPK	HPK+Sol	HPK+Sol	HPK+Sol	HPK+Sol	HPK+Sol	HPK+Sol
reference area	m²	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36
energy need for heating	kWh/(m²a)	56,63	39,26	37,06	31,78	26,89	21,85	56,63	39,26	37,06	31,78	26,89	21,85
energy use for heating and DHH													
gas	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood pellets	kWh/(m²a)	105,87	82,24	79,25	72,07	65,41	58,55	91,08	67,46	64,47	57,28	50,63	43,77
electricity	kWh/(m²a)	3,86	3,86	3,86	3,86	3,86	3,86	4,06	4,06	4,06	4,06	4,06	4,06
CO2-emissions	kg/(m²a)	6,79	5,82	5,69	5,40	5,13	4,85	6,30	5,33	5,21	4,92	4,64	4,36
primary energy demand	kWh/(m²a)	31,22	26,49	25,89	24,46	23,13	21,75	28,76	24,04	23,44	22,00	20,67	19,30
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	-30,06	-34,79	-35,39	-36,82	-38,16	-39,53	-32,52	-37,25	-37,84	-39,28	-40,61	-41,98
thermal protection standard		1	2	3	4	5	6	1	2	3	4	5	6
heat supply system		HPK+WRG	HPK+WRG	HPK+WRG	HPK+WRG	HPK+WRG	HPK+WRG	HPK+Sol+WRG	HPK+Sol+WRG	HPK+Sol+WRG	HPK+Sol+WRG	HPK+Sol+WRG	HPK+Sol+WRG
reference area	m²	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36	591,36
energy need for heating	kWh/(m²a)	59,47	42,01	39,80	34,48	29,56	24,46	59,47	42,01	39,80	34,48	29,56	24,46
energy use for heating and DHH													
gas	kWh/(m²a)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
wood pellets	kWh/(m²a)	86,33	62,58	59,58	52,35	45,65	38,71	71,55	47,80	44,79	37,56	30,87	23,93
electricity	kWh/(m²a)	4,86	4,86	4,86	4,86	4,86	4,86	5,06	5,06	5,06	5,06	5,06	5,06
CO2-emissions	kg/(m²a)	6,62	5,64	5,52	5,22	4,95	4,67	6,13	5,16	5,04	4,74	4,47	4,18
primary energy demand	kWh/(m²a)	29,91	25,16	24,56	23,11	21,78	20,39	27,46	22,71	22,10	20,66	19,32	17,93
energy reduction in primary energy compared to EnEV 09	kWh/(m²a)	-31,37	-36,12	-36,72	-38,17	-39,51	-40,90	-33,83	-38,58	-39,18	-40,62	-41,96	-43,35

Table 30: CO2-emissions for selected variants - SFH

SFH

Variant	reference area A_n m²	CO2-emissions kg/(m²a)
EnEV 09 (BWK+Sol)	187,5	20,26
Cost optimum (4/BWK+Sol)	187,5	12,18
EB 55 (5/WPE+Sol)	187,5	9,50
PH (6/BWK+WRG)	187,5	9,45
PH (6/WPE+WRG)	187,5	8,29
EB 55 (5/BWK+Sol+WRG)	187,5	8,09
EB 55 (5/BWK+Sol+WRG)	187,5	8,09
EB 40 (6/WPE+Sol+WRG)	187,5	6,30
EB 40 (6/BWK+Sol+WRG)	187,5	6,26
EB 55 (5/HPK)	187,5	5,73
PH (6/HPK+WRG)	187,5	5,09
EB 40 (6/HPK+Sol+WRG)	187,5	4,66
EB 40 (6/HPK)	187,5	4,54

Table 31: CO2-emissions for selected variants - MFH

MFH

Variant	reference area A_n m²	CO2-emissions kg/(m²a)
EnEV 09 (BWK+Sol)	591,4	13,74
Cost optimum (4/BWK+Sol)	591,4	11,99
PH (6/BWK+WRG)	591,4	9,45
EB 55 (6/WPE+Sol)	591,4	7,80
EB 55 (5/BWK+Sol+WRG)	591,4	7,78
PH (6/WPE+WRG)	591,4	7,76
EB 40 (6/WPE+Sol+WRG)	591,4	5,93
EB 55 (5/HPK)	591,4	5,13
EB 40 (6/HPK)	591,4	4,85
PH (6/HPK+WRG)	591,4	4,67
EB 55 (5/HPK+Sol)	591,4	4,64
EB 40 (6/HPK+Sol)	591,4	4,36
EB 40 (6/HPK+Sol+WRG)	591,4	4,18