IMPLEMENTING THE COST-OPTIMAL METHODOLOGY IN EU COUNTRIES

CASE STUDY AUSTRIA

BPIE

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1 Reference Building

The case study for Austria is done for the new construction of a multi-family residential building. Table 1 summarises the main characteristics of the reference building. The building represents a typical medium-size multi-storey building in an urban resp. sub-urban context.

Table 1 Characteristics of the reference building – Multifamily house

Data name	Quantity	Unit	Comments
Building geometry	See comments	---	12x32x18m, 6 floors S/V Ratio = 0,34 1/m Facade N = 576 m² Facade E = 216 m² Facade S = 576 m² Facade W = 216 m² Flat roof = 384m² Ground floor = 384 m²
Conditioned gross floor area	2,304	m²	
Description of the building	See comments	---	Residential building, reinforced concrete with external insulation, heating and hot water combined

1.1 Methodology for the calculation of energy performance

In order to calculate the energy performance of the building, the Austrian standards (which are also relevant in the context of building regulation) have been applied. The standard also includes the applicable conversion factors from final energy to primary energy. In addition, the location of Vienna has been selected (heating degree days of 3,459), which is quite representative for an average Austrian climate.

Table 2 Information on the energy performance calculation applied

Data name	Quantity	Unit	Comment
Method/tools	See comments	---	Method for calculating the energy performance of buildings in Austria, ÖNORM B 8110-6, ÖNORM H 5056 - 5059
Conversion factors	See comments	---	Primary Energy Factors Austria: - Electricity 2,62 - Gas 1,17 - District heating 0,92 - District heating high efficient CHP 0,30 - Biomass (Pellets) 1,08
Location	Vienna	---	
Heat Degree Days	3,459	HDD	
Cooling Degree Days	See comments	---	No cooling
Source of climatic dataset	See comments	---	Austrian standard for energy performance of buildings ÖNORM B 8110-5
Terrain description	See comments	---	Urban area.

Although the typical characteristics of a reference MFH built in Austrian cities have been taken into account, it has to be underlined that representativeness in a narrow sense cannot be achieved if only one reference building is selected per building category. A more comprehensive and representative picture on cost optimality would require calculations for a few different sizes and forms of reference multi-family buildings. On the other hand, it seems that the impact of the precise definition of the reference building on cost optimal levels should not be over-estimated. At least this can be concluded from several comparison calculations which have been done in Austria for small multi-family buildings (with about 580 m^2 floor area). The results referring to cost optimality are very similar to those for the larger multi-family houses as presented below.

2 Technical variants of the analysis

Altogether 50 different technical variants have been defined. The elements of differentiation are as follows:

- **Insulation standards:** Five different levels of insulation standards are defined – starting at heating energy demand HWB-line 16, which represents the minimum requirement according to the actual building regulation, and ending up at HWB-line 8, which is representative for the insulation quality of the passive house standard. HWB-number in this context means the level of achieved net heating demand lines, which according to the Austrian standards defines the thermal quality of the envelope irrespective of the compactness of the building[1]. In order to derive the variations in the thermal quality of the envelope, the single building elements (window, wall, ground floor, ceiling etc.) were improved step by step in a coherent way. The variation of the insulation standard (variants V1 to V5) is the basic variation which is then repeated in combination with other technical measures as described below.

- **Heat supply:** In the standard package (basic variants V1 – V5) district heating is used as heat supply system. This system is changed to a condensing gas boiler (V6 – V10), to a biomass boiler (V11 – V15) and to a heat pump system (V16 – V20). In order to illustrate the differences of district heating systems in terms of primary energy factors, variants V21 – V50 introduce the case of a district heating system prevailingly based on highly efficient CHP, as this is the case for the district heating system in Vienna. Whereas a “standard” district heating system is calculated with a conversion factor of 0.92, district heating systems based on highly efficient CHP are calculated with a value of 0.3. In all cases the supply systems in the house are installed as central heating systems including central tap water supply (storage and circulation pipes).
- **Insulation material:** Whereas the basic variants V1 – V5 are calculated with EPS, an additional set of variants V26 – V30 is calculated with mineral rock wool. Here, the assumption is that additional costs for the insulation material of 20% will occur.
- **Share of window area:** Variants V31 – V35 diversify the window area of the reference building since this characteristic has a major influence on the net heating demand. Several sub-variants (10%, 15%, 30% and 40%) are calculated as compared to 20% share of window area in the basic variants.
- **Ventilation system:** The installation of a mechanical ventilation system with heat recovery is typical for building and energy concepts of low-energy houses and passive houses. This allows a significant reduction of ventilation heat losses. In contrast, however, there are higher investment costs as well as in increased costs for the operation and maintenance of the facility. Whereas the basic variants V1 – V5 do not include ventilation systems, variants V36 – V40 introduce this device with an assumed heat recovery rate of 65%. This variation of the technical system has also influence on the heat distribution system inside the flats and on the required level of airtightness. V36 to V38 require a static heat distribution system (radiators) in parallel to the ventilation system, since the quality of the envelope is not sufficient to heat the house through the ventilation system alone. V40 with the highest level of quality of the envelope can dispense of the static heat distribution system, which

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[1] In order to derive the net heating demand the compactness needs to be introduced. The respective Austrian building regulation defines the net heat demand as follows: NHD = HWB-Line x $(1+3/l_c)$ where l_c is the reciprocal value of the surface-volume-ratio of the building.

means that the investment for the radiator system inside the flat is omitted. This variant, which represents typical passive house concept, requires only one heat battery per flat in the ventilation system to reheat the air. V39 represents an "interim solution" where the static heat distribution system can be reduced to one radiator per flat. With regards to airtightness a value of 1.0 is assumed for the variants V36 – V38 – as compared to 1.5 in the basic variants – whereas variants V39 and V40 require even higher levels of airtightness with a value of 0.6. The different airtightness levels are reflected in the investment costs.

- **Renewable energy sources:** Variants V41 to V50 introduce solar systems, either as solar-thermal system (100 m^2 collector surface) or as a mixture of solar-thermal and PV (50 m^2 collector surface each). In addition these solar systems are combined first with the district heating system of the basic variants and then with the biomass boiler system of variants V11 – V15.

Table 3 Summary of the technical variants analysed

No.	Measure	V1	V2	V3	V4	V5
1	Insulation standards	HWB 16 (present building regulation)	HWB 14	HWB 12	HWB 10	HWB 8
1a	Thermal Insulation - Roof	U 0,15	U 0,15	U 0,13	U 0,12	U 0,10
1b	Thermal Insulation - Wall	U 0,27	U 0,21	U 0,15	U 0,11	U 0,08
1c	Thermal Insulation - Basement	U 0,30	U 0,25	U 0,22	U 0,15	U 0,10
1d	Window	U 1,20 g0,60	U 1,15 g0,60	U 1,10 g0,60	U 1,00 g0,55	U 0,75 g0,50
2	Insulation Material	EPS	EPS	EPS	EPS	EPS
3	Share of window area	20% N+S: 36% E+W: 14%	20% N+S: 36% E+W: 14%	20% N+S: 36% E+W: 14%	20% N+S: 36% E+W: 14%	20% N+S: 36% E+W: 14%
4	Heating emission	Radiator	Radiator	Radiator	Radiator	Radiator
5	Heat supply	District heating (CHP)	District heating (CHP)	District heating (CHP)	District heating (CHP)	District heating (CHP)
6	Ventilation System	No	No	No	No	No

7	Air tightness	1.5	1.5	1.5	1.5	1.5
8	Solar systems	No	No	No	No	No
No.	**Measure**	**V6**	**V7**	**V8**	**V9**	**V10**
5	Heat supply	Condensing gas boiler	Condensing gas boiler	Condensing gas boiler	Condensing gas boiler	Condensing gas boiler
No.	**Measure**	**V11**	**V12**	**V13**	**V14**	**V15**
5	Heat supply	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)
No.	**Measure**	**V16**	**V17**	**V18**	**V19**	**V20**
5	Heat supply	Heat pump	Heat pump	Heat pump	Heat pump	Heat pump
No.	**Measure**	**V21**	**V22**	**V23**	**V24**	**V25**
5	Heat supply	District heating (CHP high efficient)	District heating (CHP high efficient)	District heating (CHP high efficient)	District heating (CHP high efficient)	District heating (CHP high efficient)
No.	**Measure**	**V26**	**V27**	**V28**	**V29**	**V30**
2	Insulation Material	Mineral rock wool	Mineral rock wool	Mineral rock wool	Mineral rock wool	Mineral rock wool
No.	**Measure**	**V31**	**V32**	**V33**	**V34**	**V35**
3	Share of window area	a) 10% b) 15% c) 30% d) 40%	a) 10% b) 15% c) 30% d) 40%	a) 10% b) 15% c) 30% d) 40%	a) 10% b) 15% c) 30% d) 40%	a) 10% b) 15% c) 30% d) 40%
No.	**Measure**	**V36**	**V37**	**V38**	**V39**	**V40 (Passive House)**
6	Ventilation System	Mech. 65% heat recovery	Mech. 65% heat recovery	Mech. 65% heat recovery	Mech. 65% heat recovery	Mech. 65% heat recovery
4	Heating emission	Radiator	Radiator	Radiator	Air, one radiator	Air
7	Air tightness	1.0	1.0	1.0	0.6	0.6
No.	**Measure**	**V41**	**V42**	**V43**	**V44**	**V45**
10	Solar systems	100 m² Therm.	100 m² Therm.	100 m² Therm.	50 m² Therm. 50 m² PV	50 m² Therm. 50 m² PV
No.	**Measure**	**V46**	**V47**	**V48**	**V49**	**V50**
5	Heat supply	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)	Biomass (Pellets)
10	Solar systems	100 m² Therm.	100 m² Therm.	100 m² Therm.	50 m² Therm. 50 m² PV	50 m² Therm. 50 m² PV

3 Primary energy demand calculation

In order to calculate the energy performance of the building, the Austrian standards (which are also relevant in the context of building regulation) have been applied. Therefore, the method used for C-O was based on the method for calculating the energy performance of buildings in Austria, ÖNORM B 8110-6, and ÖNORM H 5056 – 5059.

The standards also include the applicable conversion factors from final energy to primary energy. In addition, the location of Vienna has been selected (heating degree days of 3,459), which is quite representative for an average Austrian climate.

The energy need considered in the calculations is the energy for heating, domestic hot water, ventilation and auxiliary systems of the building. Energy consumption for cooling purposes is not taken into account, because the Austrian building regulation prescribes that residential buildings have to be built in such a way that demand for cooling is avoided. Furthermore, the consumption of electric household appliances is not included in the calculations below[2].

The conversion factors for primary energy are fixed by relevant Austrian standards as follows:

- Electricity: 2.62
- Gas: 1.17
- District heating (CHP): 0.92
- District heating (highly efficient CHP): 0.30
- Biomass (Pellets): 1.08

4 Input data for the cost calculation

4.1 Construction and maintenance cost

Construction and maintenance cost data are based mainly on a market-based analysis which e7 has conducted together with the company M.O.O.CON. The analysis serves for a building-element cost data-base for life-cycle cost assessment applied in early planning phases. The enquiry of construction cost data started in 2010 and is updated continuously due to the involvement of several construction companies[3]. With respect to cost of ventilation systems in multi-family houses, where there is actually rather limited market-based data

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[2] The energy consumption for electric household appliances is included in the primary energy and CO_2 values included in the energy certificate (with a fixed number)

[3] comp. Hofer, G., Herzog, B., Planungsunterstützende Lebenszykluskostenanalyse für nachhaltige Gebäude, Wien 2011 http://www.e-sieben.at/de/download/Hofer_Herzog_Planungsunterstttzende_Lebenszykluskostenanalyse.pdf

available, a few additional sources of information based on scientific literature have been used[4].

4.1.1 Construction costs related to the quality of the building envelope

The input factors associated with the thermal properties of the building envelope are summarized in table 4. U-values for façade insulation, roof insulation and basement ceiling insulation as well as the costs incurred for this are allocated to the five different levels of net heat demand lines – called HWB-line 16, HWB-line 14, HWB-line 12, HWB-line 10 and HWB-line 8 (see explanations in chapter 0, point 1). Only those cost elements are recognized as costs, which are different for the analysed variants.

Table 4 Assumed construction costs dependent on the quality of the building envelope

	VARIANTS 1-5 (stepwise improvement of the envelope)	
THERMAL	**U-value (W/m²K)**	**COSTS (€/m²)**
Façade insulation		
HWB-line 16	0.27	66
HWB-line 14	0.21	70
HWB-line 12	0.15	78
HWB-line 10	0.11	89
HWB-line 08	0.08	113
Roof insulation		
HWB-line 16	0.15	185
HWB-line 14	0.15	185
HWB-line 12	0.13	195
HWB-line 10	0.12	201
HWB-line 08	0.10	218
Cellar ceiling insulation		
HWB-line 16	0.30	40
HWB-line 14	0.25	50
HWB-line 12	0.22	56
HWB-line 10	0.15	70
HWB-line 08	0.10	80
Windows		
HWB-line 16	1.20	537
HWB-line 14	1.15	540
HWB-line 12	1.10	544
HWB-line 10	1.00	551
HWB-line 08	0.75	650

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[4] comp. Schöberl, Helmut (2011), Reduktion der Wartungskosten von Lüftungsanlagen in Plus-Energiehäusern, Projektbericht im Rahmen der Programmlinie Haus der Zukunft, Wien, Oktober 2011 and Schöberl, Helmut; Lang, Christoph; Handler, Simon (2012): Ermittlung und Evaluierung der baulichen Mehrkosten von Passivhausprojekten, Projektbericht im Rahmen der Programmlinie Haus der Zukunft, Wien, August 2012

For the basic variants EPS is used as insulation material. For the variants V26 to V30 mineral rock wool has been used instead. For these variants a general extra cost of 20% has been assumed, which is in line with information from construction firms in Austria.

4.1.2 Construction and maintenance cost related to heating systems, ventilation systems and solar systems

Table 5 Cost assumptions related to heating systems, ventilation systems and solar systems

VENTILATION SYSTEM	**CONSTRUCTION COST (€/m^{2}GFA)**	**MAINTENANCE (€/m^{2}GFA)**	**YEARLY REPAIRS (€/m^{2}GFA)**
Air ducts and other long lasting elements	35	0	0
Ventilation plant (in case of a parallel static heating system)	20	0.5	0.2
Ventilation plant (for the heating of the building)	25	0.5	0.25
HEATING SYSTEM **(Cost data valid for heat load between 45 and 80 kW)**	**CONSTRUCTION COST**	**MAINTENANCE (€/a)**	**YEARLY REPAIRS (€/a)**
Gas condensing boiler	155 €/kW	255	385
District heating: transfer station	100 €/kW	150	150
Biomass boiler	550 €/kW	500	600
Heat pump	325 €/kW	250	400
Geothermal probe for heat pump	775 €/kW	-	-
Heat distribution system in the flat (incl. radiators)	30 €/m^{2}GFA	-	-
SOLAR-THERMAL	**CONSTRUCTION COST (€/m^{2}collector area)**	**ANNUAL MAINTENANCE (€/m^{2}collector area)**	**YEARLY REPAIRS (€/m^{2}collector area)**
100 m^2 collector area	500	3.75	1.67
50 m^2 collector area	550	3.75	1.67
PHOTOVOLTAICS	**CONSTRUCTION COST (€/m^{2}collector area)**	**ANNUAL MAINTENANCE (€/m^{2}collector area)**	**YEARLY REPAIRS (€/m^{2}collector area)**
	340	1.0	-

For variant V39 und V40 (passive house concepts) the cost for the heat distribution system inside the flat has been adapted. V39 calculates with a reduced cost of 10 €/m^2 for the single radiator that is still necessary. V40 with exclusive air heating does not take into account any cost for the static heat distribution system in the flat.

4.2 Energy Prices

As far as the starting year is concerned, the following average prices are stated:

- District heating: 0.11 € / kWh. For simplification, a mixed price between work and power input is applied. The meter charges were not included because they do not depend on the thermal-energy performance of the building. The stated mixed price was compared to several heating rates and belongs more to the higher heating rates in Austria. For instance, based on the reference building, a price of just about 0.10 €/kWh is obtained for district heating in Vienna.
- Gas price: 0.07 €/kWh. This price is a mixed price, too.
- Biomass / pellets price: 0.05 €/kWh
- Electricity: Different prices apply here – once again calculated on a mixed basis for work and power. As specified in table 6 the standard price is assumed for auxiliary electricity consumption (for the operation of the ventilation system and the boilers). A special cheaper tariff is assumed for heat pumps. And finally, a feed-in tariff for electricity of the PV-plant that is not used in the house itself is taken into account.

The assumption with respect to the annual increase in energy prices is 2.8% in the reference scenario. This assumption will be diversified in the sensitivity analysis.

Another case for the sensitivity analysis is the energy price assumption for the macroeconomic (societal) perspective in which practically the same prices are applied but with exclusion of the value added tax.

Table 6 Energy prices, private perspective, VAT included

Parameter	Value for calculation	Comments/Source
Gas	0,07 EUR/kWh	Assumption
District heating	0,11 EUR/kWh	Assumption
Biomass (Pellets)	0,05 EUR/kWh	Assumption
Electricity	0,19 EUR/kWh	Assumption
Electricity (special tariff heat pump)	0,16 EUR/kWh	Assumption
Electricity (feed-in tariff)	0,10 EUR/kWh	Assumption
Energy price development	2.8 %/a	In real term

Table 1 Energy prices, macroeconomic view(excl. VAT)

Parameter	Value for calculation	Comments/Source
Gas	0,058 EUR/kWh	Assumption
District heating	0,092 EUR/kWh	Assumption
Biomass (Pellets)	0,042 EUR/kWh	Assumption
Electricity	0,158 EUR/kWh	Assumption
Electricity (special tariff heat pump)	0,133 EUR/kWh	Assumption
Electricity (feed-in tariff)	0,083 EUR/kWh	Assumption

4.3 Lifetime of building elements

The life-time of building elements is differentiated at the level of building elements according to **Table 2**. This means that major system elements may have different lifetimes – for example the heat boiler has a shorter lifetime than the heat distribution system. **Table 2** presents the most important assumptions with respect to the lifetime of building elements.

Table 2 Assumed lifetimes of building elements

Parameter	Value for calculation
Insulation (thermal protection), Air tightness	50 years
Window	35 years
Heating and ventilation distribution	35 years
Heat plant, central ventilation system	20 years
Heat pump, Geothermal probe	50 years

4.4 Other Input Data

Error! Reference source not found. summarises the other relevant input data for the cost ptimality calculation as follows:

- The **observation period** is specified in the EU regulation. For residential buildings, it is defined as a period of 30 years. Generally speaking, it should be noted that the impact of the length of the observation period on the end result is limited due to the longer lifetime of the building elements and their respective residual values..
- As for the **discount rate**, the EU regulation provides the Member States with a wide scope for national provisions. In the present analysis, the discount rate was set at 3% in real terms. This approach reflects the current interest rates for long-term mortgage secured loans and has to be regarded as a realistic underlying asset

– depending on the creditworthiness and the expectation of profit of the client. Within the scope of a sensitivity analysis, the influence of different discount rates on the calculation result gets examined.

- In real terms we assume that the **price for maintenance and replacement** will not increase – i.e. the nominal price increase will be in line with the general inflation rate.
- Since the construction cost as presented in chapter 4.1 do not include the cost for design, an average additional **cost for design** of 10% has been assumed.

Table 9 Other relevant input data for the cost optimality calculation

Parameter	Value	Comments/Source
Starting year for calculation	2012	
Calculation period	30 years	according to Annex I of EU regulation
Discount rate	3.0 % p.a.	real
Price development for maintenance and replacement	0 % p.a.	real
Design costs	10%	additional to construction costs

5 Results of the baseline scenario from a private investors perspective

Based on the aforementioned assumptions, the life cycle costs for the variants to be examined were determined in accordance with the approach outlined in the respective EU regulations. The life cycle costs include the construction costs, upkeep costs, maintenance costs, renewal costs for those building elements that need to be replaced within the observation period as well as energy costs. In the following Figure 1 to Figure 6, the essential calculation results for the baseline scenario are presented. The figures show the global cost differences as compared to the actual minimum requirements according to building regulations which is at the level of net heating demand line HWB 16.

The main results can be described as follows:

- First of all and most important, the general picture shows that the cost curves for comparable variants each run extremely shallow. If we look, for example, at the cost curve for the basic variants which represents a stepwise improvement of the building envelope starting from actual minimum requirements (HWB-line 16; V1) and ending up at a passive house envelope (HWB-line 8; V5), the cost range is only at a level of about 20 €/m^2 over the whole calculation period of 30 years. This represents just 5 cents/m^2 and month. The basic variants have a very slight cost optimum at the net heating demand line HWB-line 12. However, the differences in costs are very low, especially in the area between net heating demand HWB-lines

10 to 14. It is also true that concerning the reference building which is supplied with district heating, the HWB-line 8 is not far from the cost optimum (see **Error! eference source not found.**).

- When analysing the impact of different heating systems, we can notice that the general picture remains widely unchanged. In the range between net heating demand lines 14 and 10 the cost curve is extremely shallow. Only when comparing the net heating demand line 8 to the cost optimum, a slight “cost jump” can be observed for the reference buildings supplied by gas, biomass and heat pump. This is simply due to cheaper variable energy costs as compared to the variants with district heating (see Figure 2).
- The choice of insulation material has practically no influence on the cost optimal level (see Figure 3).
- The variants where window areas have been diversified (see **Error! Reference ource not found.**) illustrate that the forms of the cost curves themselves do not change remarkably. However, the figure demonstrates clearly, how global costs increase with bigger window areas.
- Regarding the variants with ventilation systems, those concepts where an additional static heating system is omitted, are the cheapest, since the cost of heating distribution can be reduced in this case. This is even true if one considers that concepts with air heating are only feasible if the building has a very good shell quality (see Figure 5). The global cost of the most efficient variants with ventilation systems are about 30 to 40 €/m2 higher than of comparable variants without ventilation systems.
- The basic variants featuring solar systems present themselves as quite economical and also lead to a significant improvement in the primary energy demand. In the case of the reference building with district heating, the variant V43 (net heating demand 12 combined with a solar-thermal system) even turns out to be the cost optimum for all variants examined within the scope of the baseline scenario. The picture is a bit less favourable for the variants where solar systems are combined with biomass heating systems. But even these variants are very close to the cost optimum (see Figure 5 and 6).

Figure 1 Results of cost optimality calculation for the basic variants: Stepwise improvement of the insulation standard ranging from actual minimum requirements (HWB-line 16; V1) to passive house envelope (HWB-line 8; V5) – Global cost difference compared to actual minimum requirements

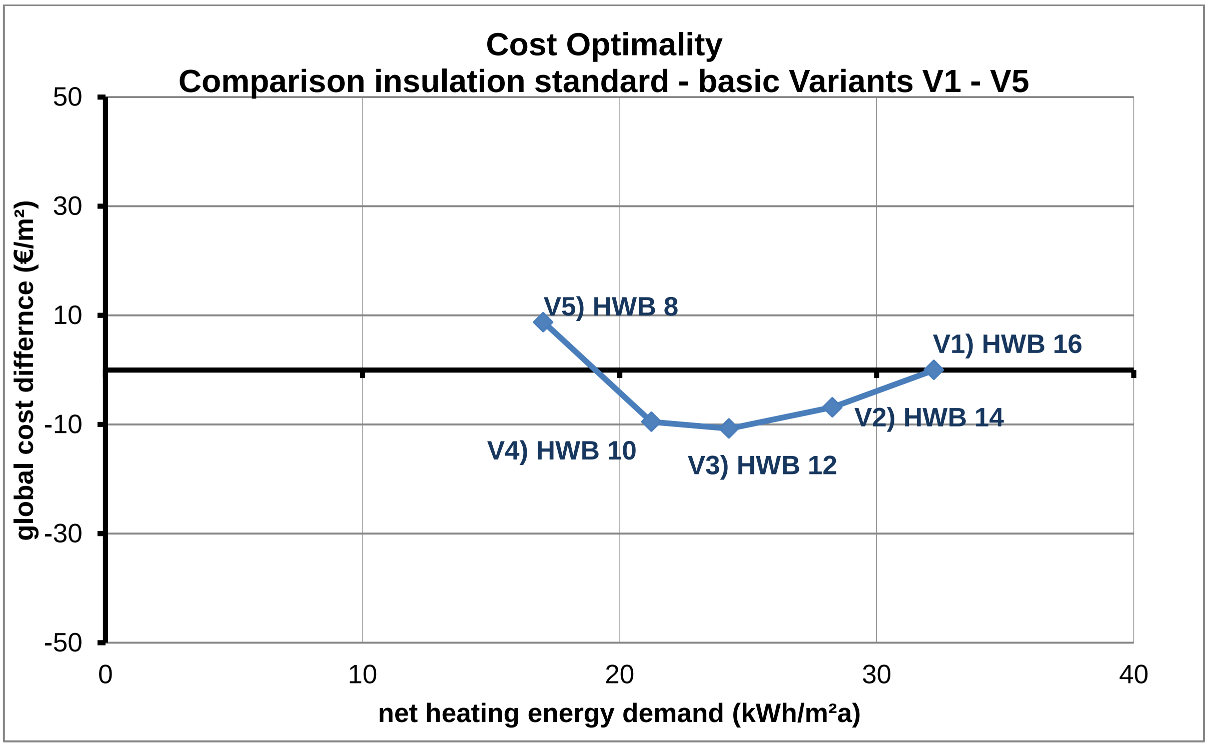


Figure 2 Results of cost optimality calculation for different envelope qualities and different heat supply systems – Global cost difference compared to actual minimum requirements

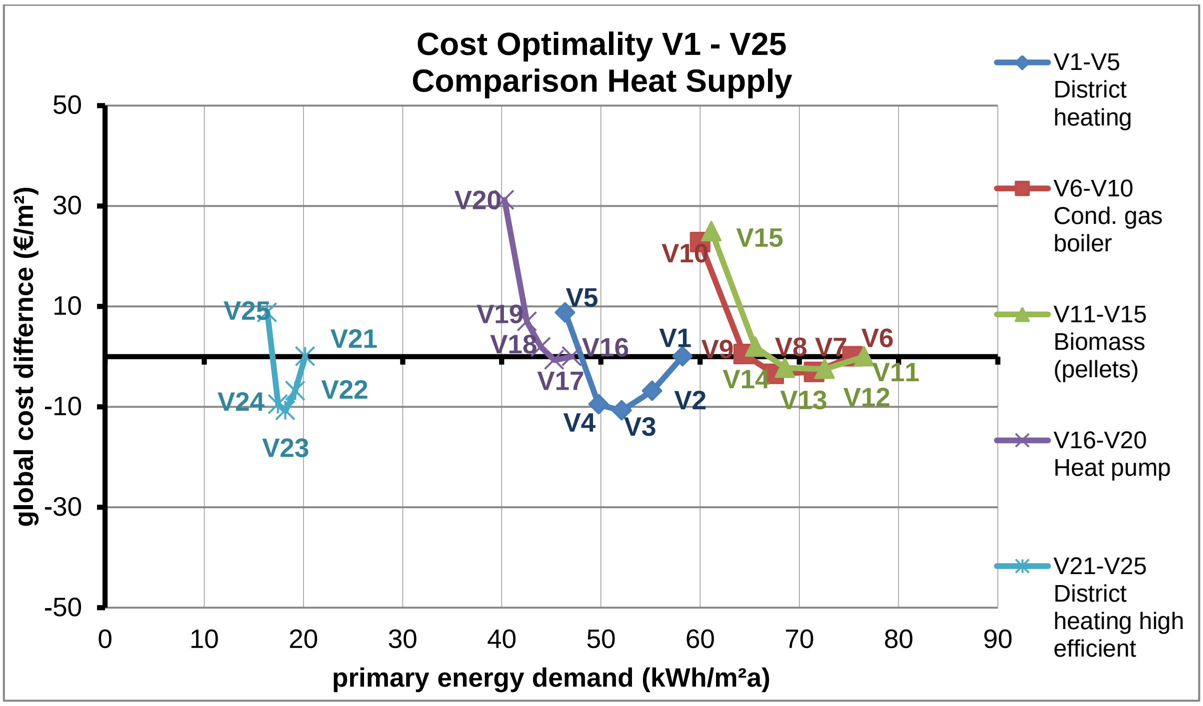


Figure 3 Results of cost optimality calculation for different materials – Global cost difference compared to actual minimum requirements

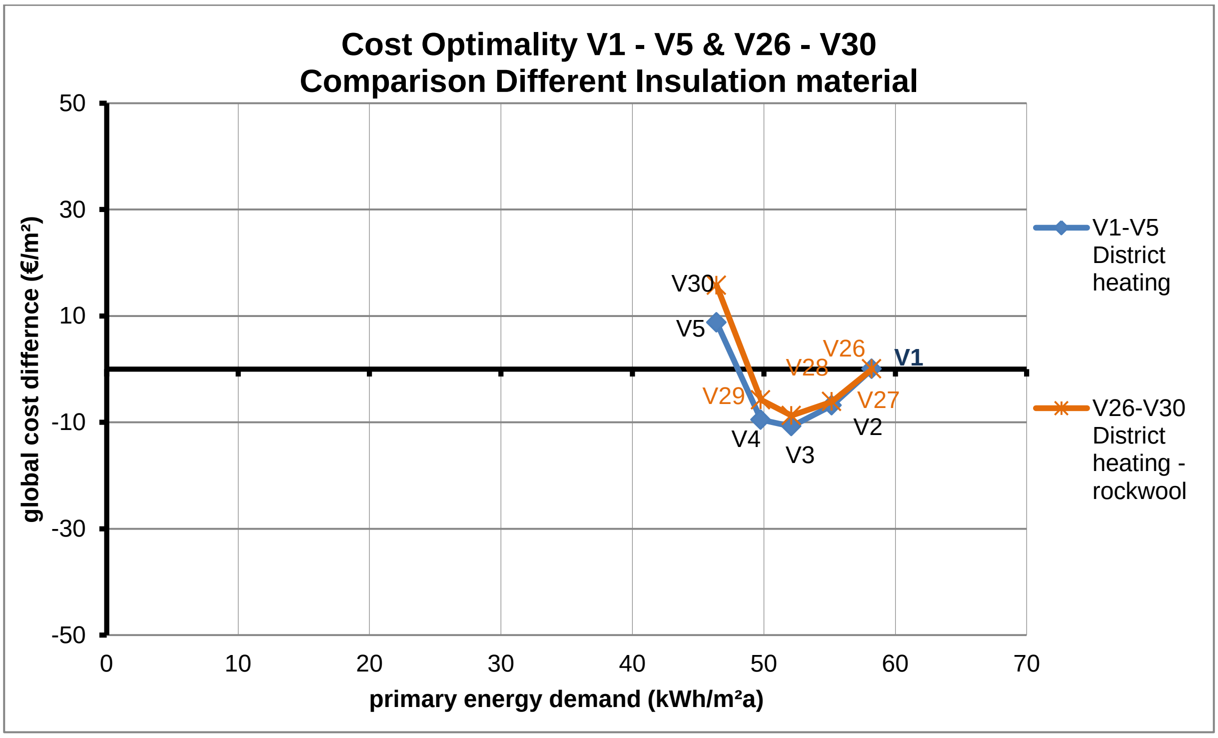


Figure 4 Results of cost optimality calculation for different assumptions with respect to window area share – Global cost difference compared to actual minimum requirements

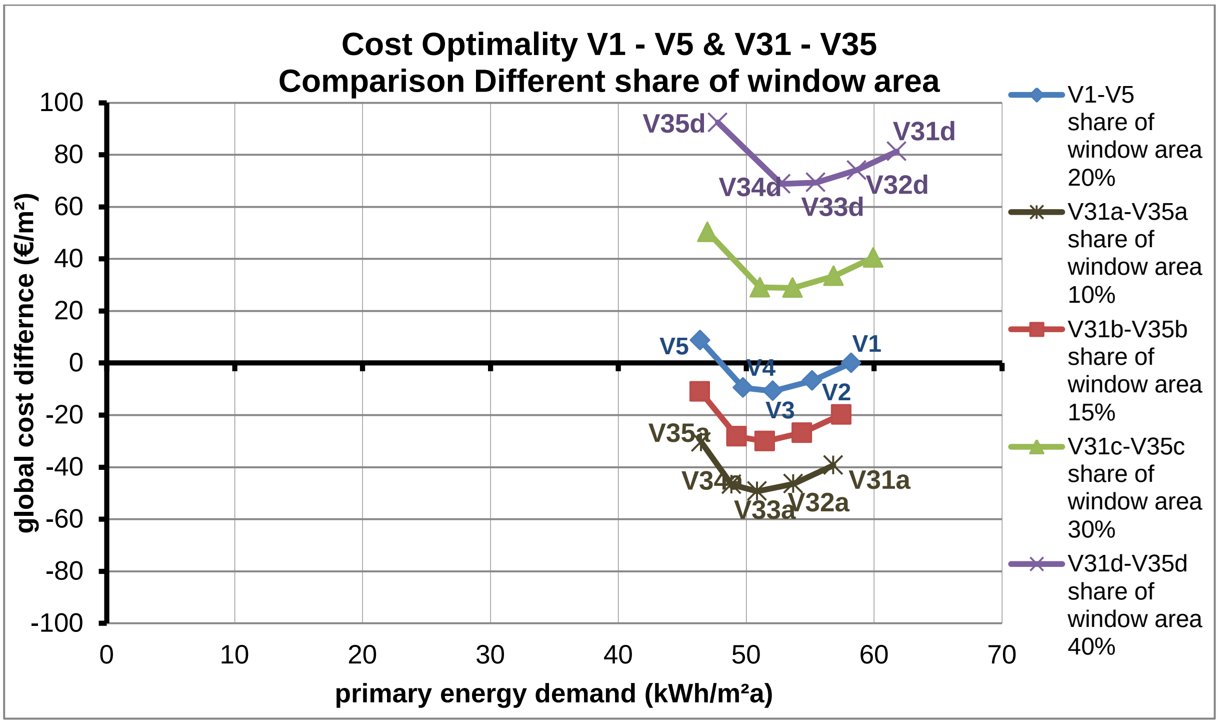


Figure 5 Results of cost optimality calculation for the basic variants (district heating) combined with ventilation systems and with solar systems – Global cost difference compared to actual minimum requirements

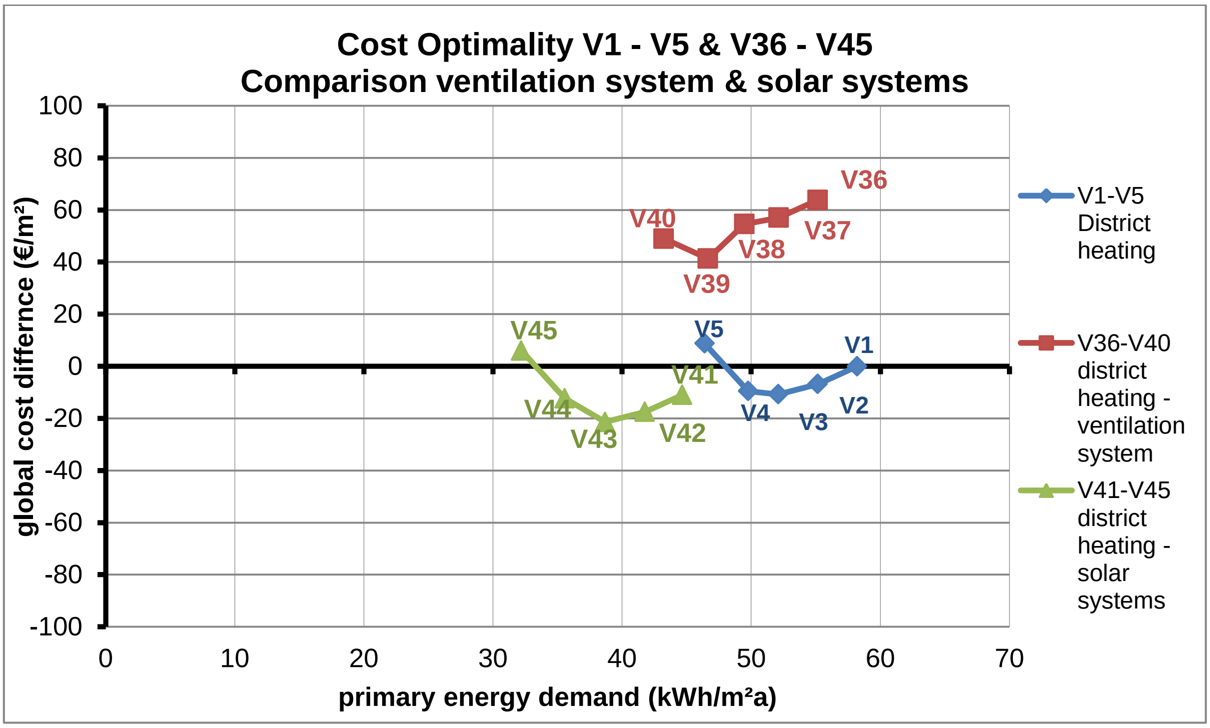
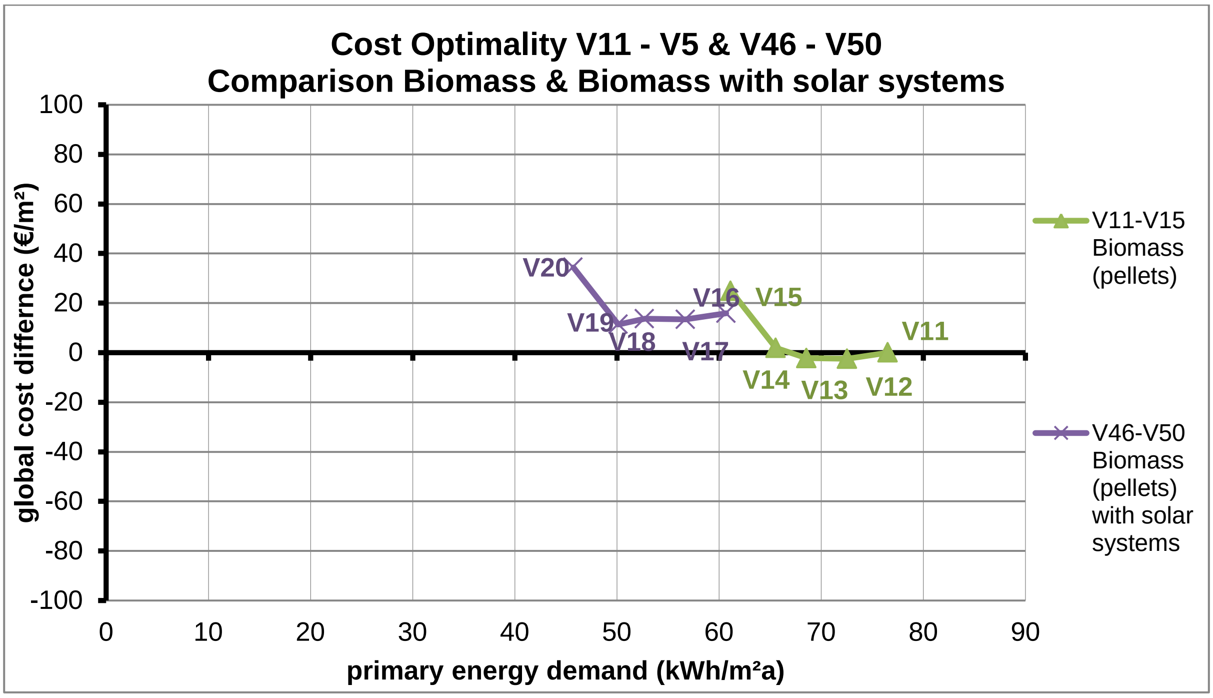


Figure 6 Results of cost optimality calculation for the variants of biomass heated building combined with solar systems – Global cost difference compared to actual minimum requirements



6 Sensitivity analysis and results of macroeconomic view

In addition to the 50 technical variants as described above, a series of sensitivity analyses have been conducted in order to check the reliability and stability of the results of the baseline scenario. With the sensitivity analyses the impact of important framework conditions are tested, such as the discount rate or the energy price development. In order to reduce the effort, the sensitivity analyses have been realised only for the variants V1 – V5 (basic variants), V36 – V40 (variants with ventilation systems including the so-called passive house concepts) and V46 – V50 (biomass in combination with solar systems).

A specific case is the macroeconomic (societal) perspective which is assessed by means of sensitivity analyses Macro1 to Macro3. The differences between these three scenarios of the macroeconomic view refer to variations in the discount rate and in energy price development.

Table 10 Overview on sensitivity analyses conducted

Parameter	Value for basic calculation	Value for sensitivity analysis
Sens1: Cost of environmental damage	0 EUR/tCO$_2$	Carbon price according recommendation of EU-regulation, Annex II
Sens2: Energy price development	2.8 % p.a.	4 % p.a.
Sens3: Discount rate	3.0 % p.a.	1.0 % p.a.
Sens4: Discount rate and energy price development	3.0 % p.a. 2.8 % p.a.	1.0 % p.a. 4.0 % p.a.
Sens5: Investment cost		Reduction of cost differences between variants (e.g. due to regional cost differences)

Macro1: Macroeconomic-perspective 1	Discount rate 3.0% VAT included no subsidies 0 EUR/tCO_2	Discount rate 3.0% p.a. Energy price trend 2.8% p.a. no tax / no subsidies Carbon price according recommendation of EU-regulation, Annex II
Macro2: Macroeconomic-perspective 2	Discount rate 3.0% VAT included no subsidies 0 EUR/tCO_2	Discount rate 1.0% p.a. Energy price trend 2.8% p.a. no tax / no subsidies Carbon price according recommendation of EU-regulation, Annex II
Macro3: Macroeconomic-perspective 3	Discount rate 3.0% VAT included no subsidies 0 EUR/tCO_2	Discount rate 1.0% p.a. Energy price trend 4.0% p.a. no tax / no subsidies Carbon price according recommendation of EU-regulation, Annex II

Figure 7 to Figure 12 and the Table 11 to Table 13 show the results of the sensitivity analyses in a condensed form. The first set of figures shows the results of the sensitivity analysis with respect to the private investor’s perspective (basic scenario compared to Sens1 to Sens5). The second set of graphs shows the results of the sensitivity analyses related to the macroeconomic perspective (Macro1 to Macro2).

On the whole, it can be summarised that the influence of the tested input parameters is almost negligible mainly with respect to the form of the cost curve and with respect to remarkable shifts of the cost optimum. It has to be stressed that the cost curves are still very shallow. Considering the influence factors tested (and with the assumptions made) the single most important factor seems to be the discount rate (Sens4), but also the assumed cost differences related to different qualities are important (Sens5). The sensitivity analyses related to the macroeconomic perspective (Macro1 to Macro3) with a combination of low discount rate, exclusion of VAT and inclusion of CO_2-cost show – in general – an improvement of the cost curve mainly with respect to the most efficient solutions – i.e. the variants with the lowest primary energy demand and lowest CO_2-emissions.

Figure 7 Results of the sensitivity analyses for the basic variants (district heating)

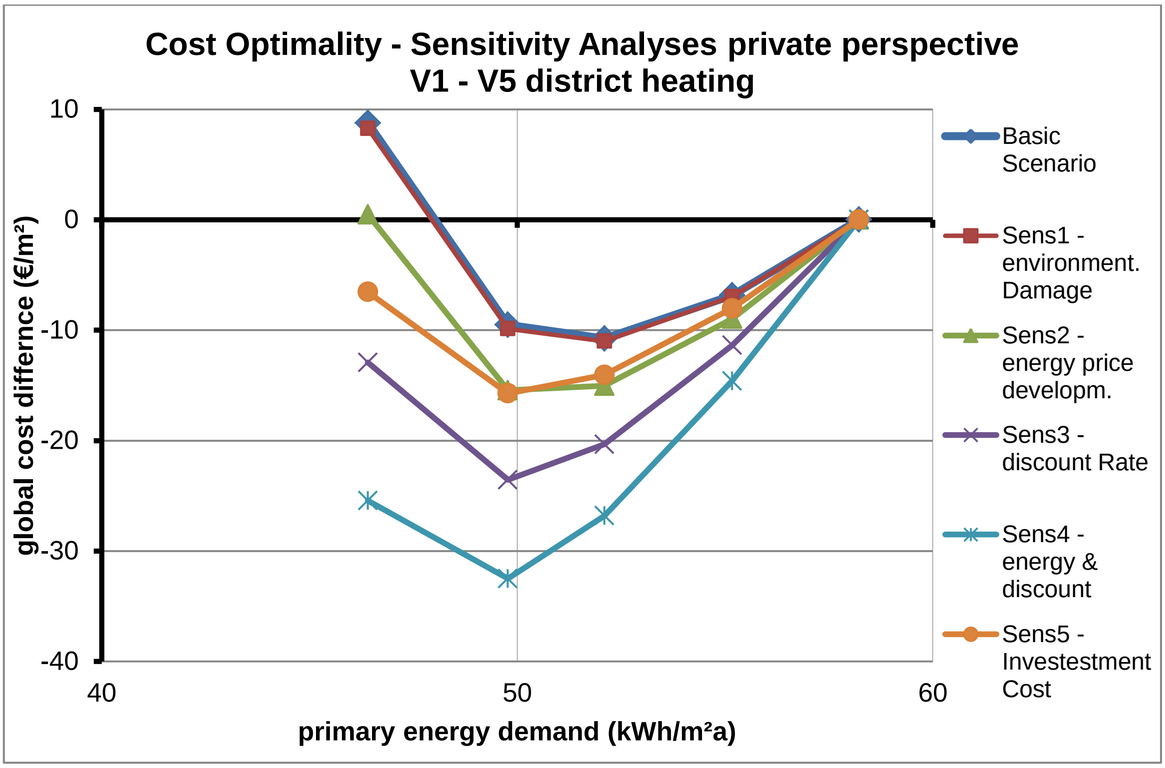


Figure 8 Results of the Macro-economic-perspective sensitivity analyses for the basic variants (district heating)

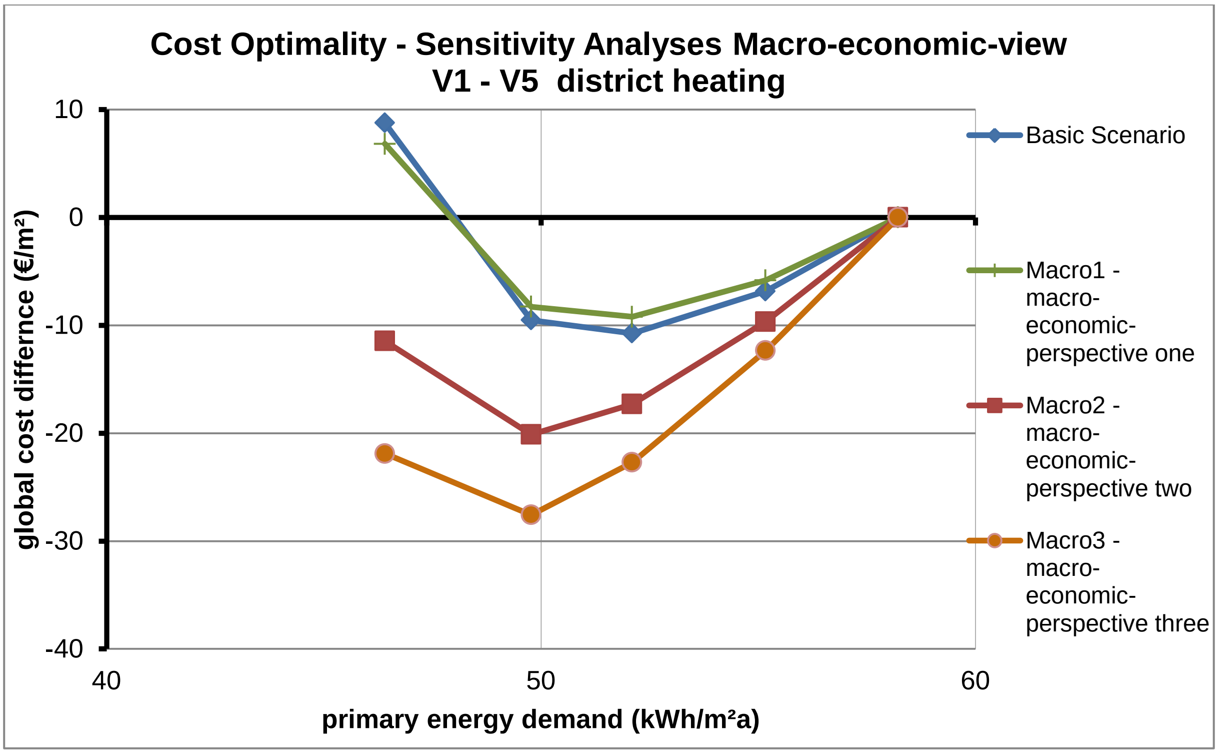


Table 11 Results of the sensitivity analyses for the basic variants (district heating) – cost optimal variants are highlighted

Sensitivity Analyses		**V1 HWB 16**	**V2 HWB 14**	**V3 HWB 12**	**V4 HWB 10**	**V5 HWB 8**
Primary energy demand	[kWh/m²a]	58,22	55,17	52,10	49,77	46,41
Gap to HWB 16	(%)		-5,2%	-10,5%	-14,5%	-20,3%
Global Cost Basic Scenario	[€/m²]	382,68	375,84	**371,93**	373,16	391,44
Global costs Sens1 - Cost of environm. damage	[€/m²]	385,17	378,21	**374,17**	375,30	393,45
Global costs Sens2 - Energy price development	[€/m²]	422,95	413,97	407,91	**407,50**	423,43
Global costs Sens3 - Discount Rate	[€/m²]	442,00	430,62	421,67	**418,45**	429,08
Global costs Sens4 - Energy price & discount rate	[€/m²]	502,82	488,22	476,01	**470,31**	477,38
Global costs Sens5 – Red. difference invest. cost	[€/m²]	382,68	374,64	368,62	**366,96**	376,14
Global costs Macro1	[€/m²]	321,39	315,57	**312,18**	313,11	328,21
Global costs Macro2	[€/m²]	371,81	362,16	354,52	**351,70**	360,36
Global costs Macro3	[€/m²]	422,50	410,15	399,80	**394,92**	400,62

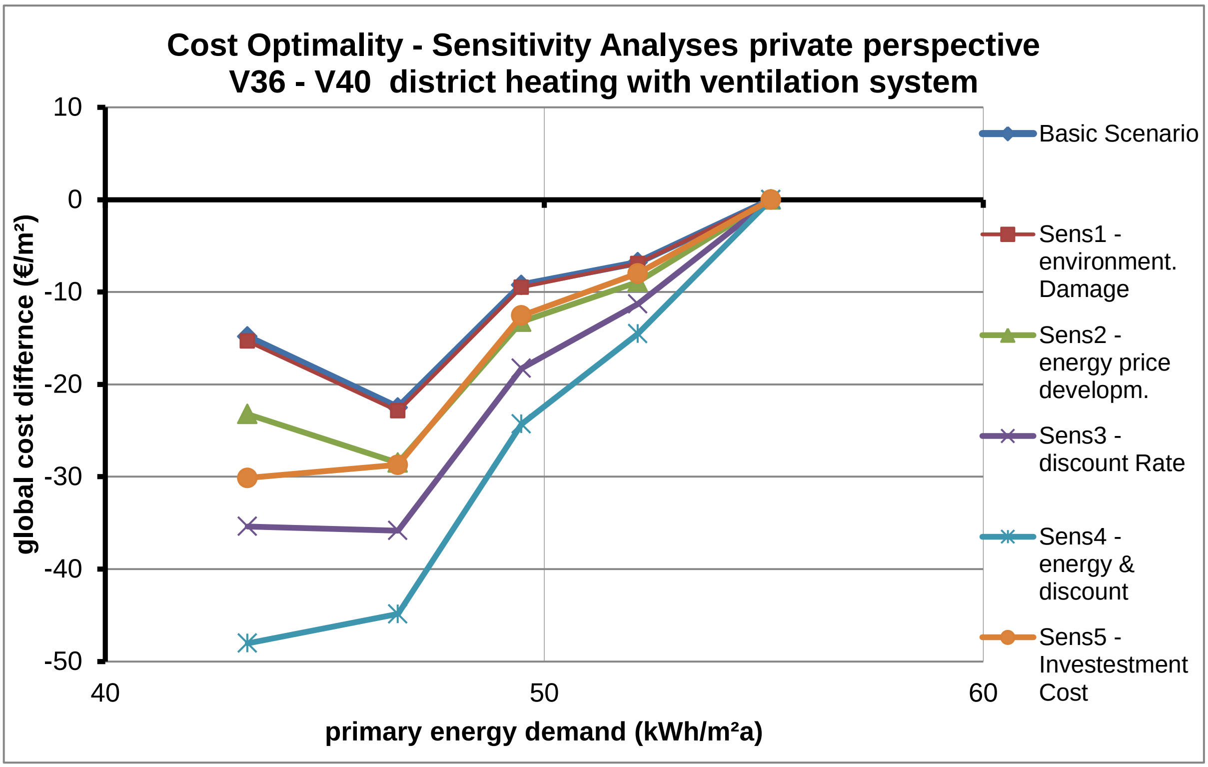


Figure 1 Results of the sensitivity analyses for the variants with ventilation system

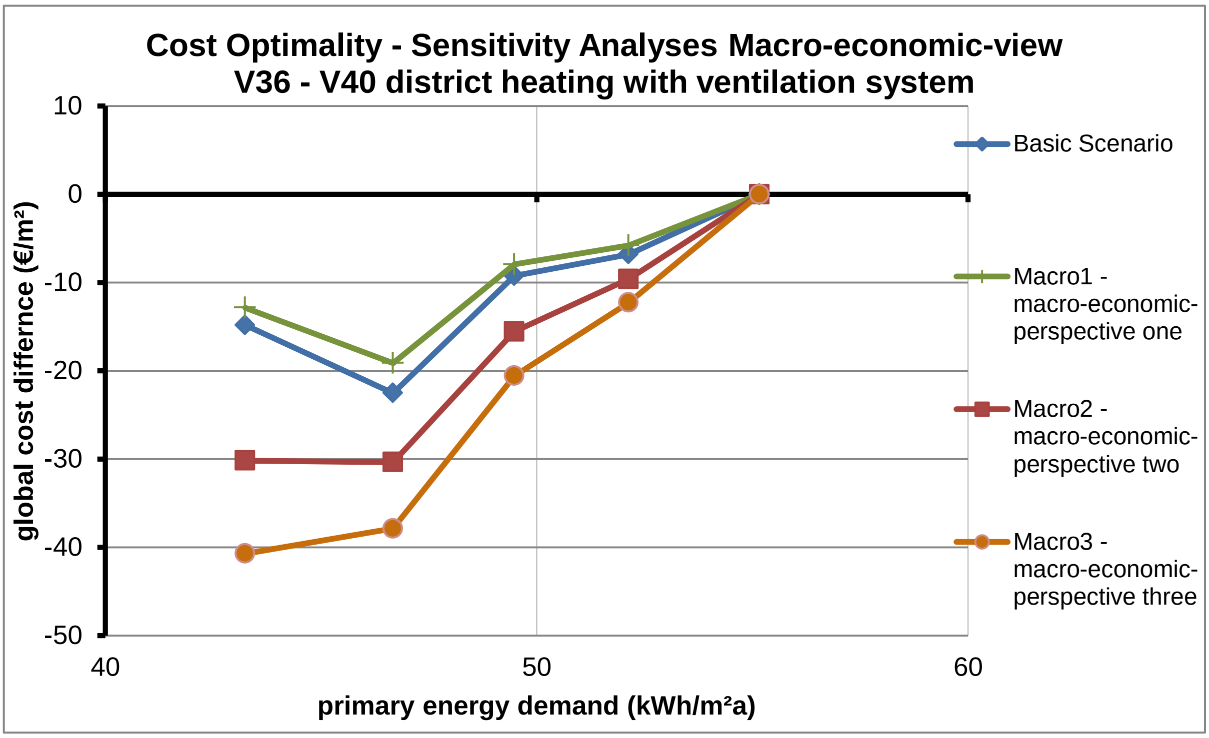


Figure 2 Results of the Macroeconomic perspective sensitivity analyses for the variants with ventilation system

Table 3 Results of the sensitivity analyses for the variants with ventilation system – cost-optimal variants are highlighted

Sensitivity analyses		**V36 HWB 16**	**V37 HWB 14**	**V38 HWB 12**	**V39 HWB 10**	**V40 HWB 8**
Primary energy demand	[kWh/m²a]	55,16	52,13	49,48	46,67	43,24
Gap to HWB 16	(%)		-5,5%	-10,3%	-15,4%	-21,6%
Global Cost Basic Scenario	[€/m²]	446,51	439,72	437,27	**423,99**	431,68
Global costs Sens1 - Cost of environm. damage	[€/m²]	449,10	442,19	439,63	**426,23**	433,78
Global costs Sens2 - Energy price development	[€/m²]	483,18	474,27	469,96	**454,70**	459,97
Global costs Sens3 - Discount Rate	[€/m²]	503,46	492,16	485,20	**467,63**	468,09
Global costs Sens4 - Energy price & discount rate	[€/m²]	558,85	544,34	534,57	514,00	**510,82**
Global costs Sens5 – Red. difference invest. cost	[€/m²]	446,51	438,53	433,96	417,80	**416,38**
Global costs Macro1	[€/m²]	374,68	368,90	366,75	**355,57**	361,83
Global costs Macro2	[€/m²]	423,17	413,57	407,62	**392,81**	393,00
Global costs Macro3	[€/m²]	469,32	457,05	448,76	431,46	**428,61**

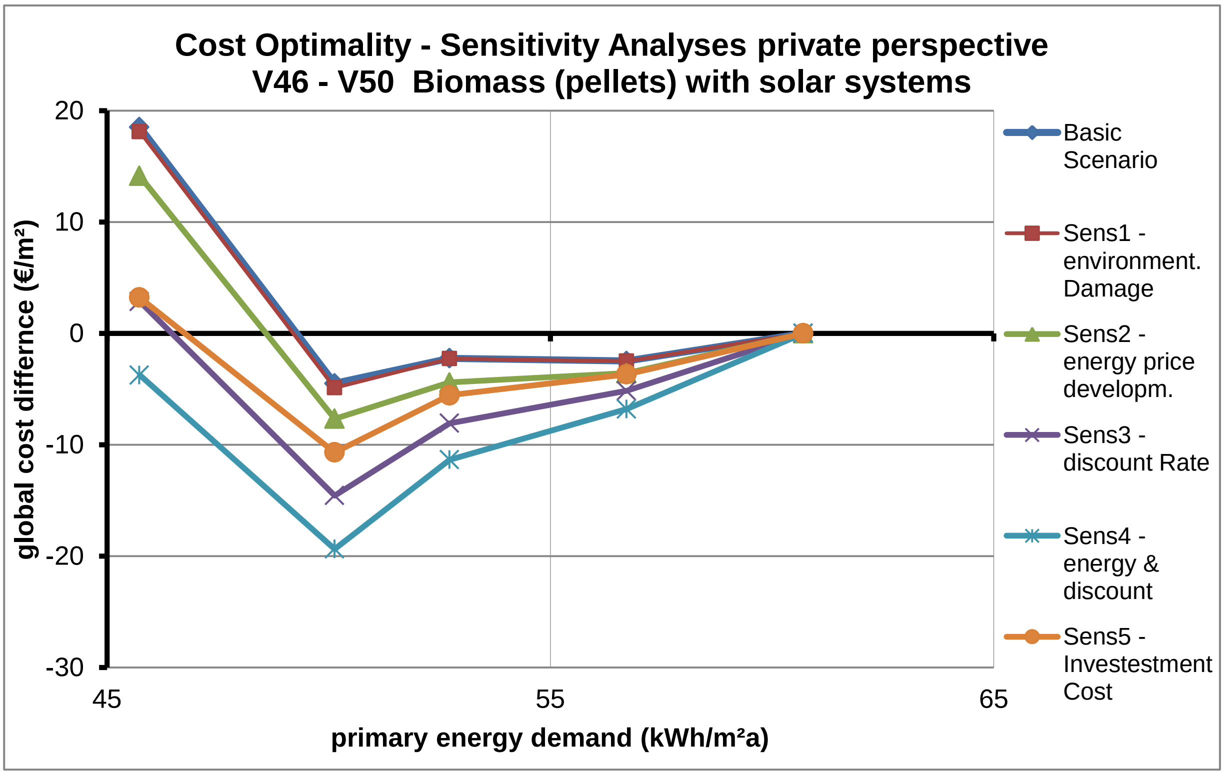


Figure 3 Results of the sensitivity analyses for the variants with biomass heating system combined with solar systems

Figure 12 Results of the Macroeconomic perspective sensitivity analyses for the variants with biomass heating system combined with solar systems

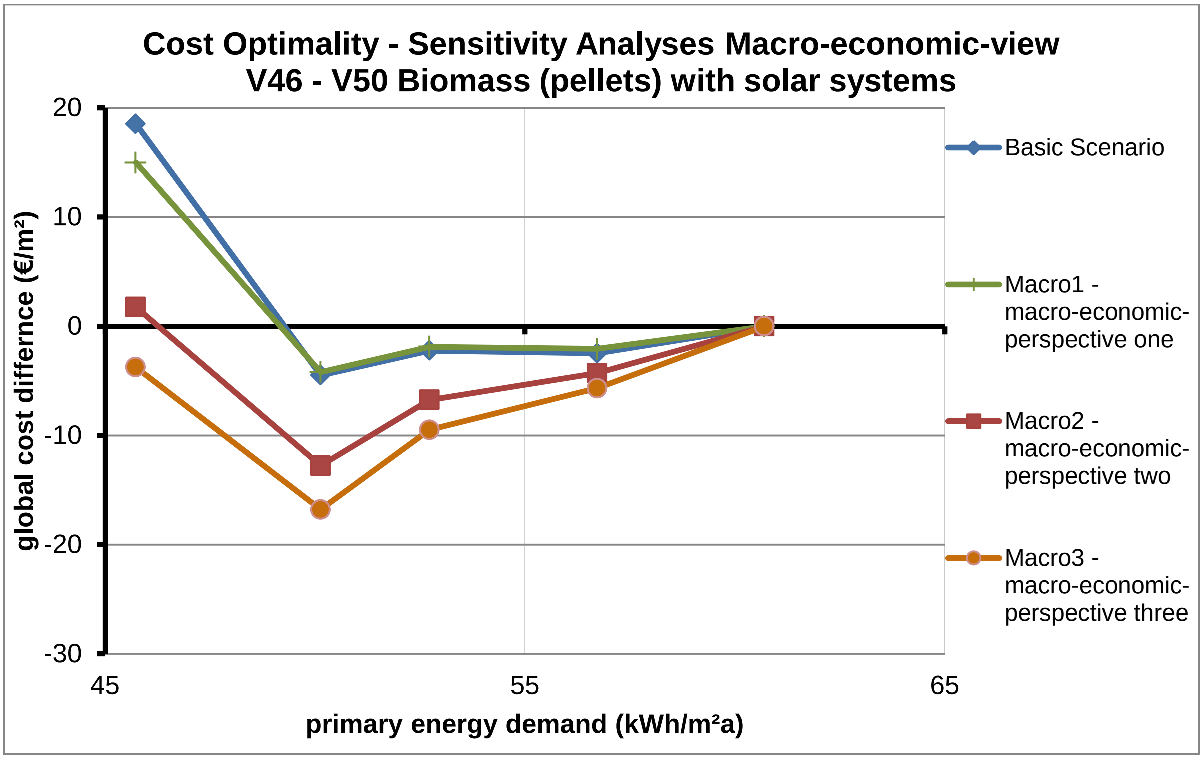


Table 4 Results of the sensitivity analyses for the variants with biomass heating system combined with solar systems – cost optimal variants are highlighted

Sensitivity analyses		**V46 HWB 16**	**V47 HWB 14**	**V48 HWB 12**	**V49 HWB 10**	**V50 HWB 8**
Primary energy demand	[kWh/m²a]	60,71	56,72	52,73	50,13	45,73
Gap to HWB 16	(%)		-6,6%	-13,1%	-17,4%	-24,7%
Global Cost Basic Scenario	[€/m²]	331,02	328,54	328,78	**326,54**	349,55
Global costs Sens1 - Cost of environm. damage	[€/m²]	331,42	328,93	329,16	**326,54**	349,55
Global costs Sens2 - Energy price development	[€/m²]	348,01	344,44	343,60	**340,34**	362,15
Global costs Sens3 - Discount Rate	[€/m²]	354,96	349,82	346,90	**340,40**	357,83
Global costs Sens4 - Energy price & discount rate	[€/m²]	380,61	373,83	369,26	**361,24**	376,87
Global costs Sens5 – Red. difference invest. cost	[€/m²]	331,02	327,35	325,47	**320,34**	334,24
Global costs Macro1	[€/m²]	276,25	274,17	274,37	**272,05**	291,23
Global costs Macro2	[€/m²]	296,36	292,05	289,61	**283,59**	298,11

Global costs Macro3	[€/m²]	317,73	312,06	308,25	**300,96**	313,98

7 Conclusions

When assessing the results of the cost optimality calculations for the reference multi-family house on a whole, the following conclusions can be drawn:

- As a general picture, the flat curve progressions of the cost curves are remarkable. It should be emphasized that the costs shown are life cycle costs over the entire observation period of 30 years. Differences in costs of 90 € / m^2, which occur at the maximum (!) between variants of the reference buildings, therefore correspond to additional costs of just 0.25 € per m^2 and month. However, calculations show that some of the most energy efficient variants – which are either variants with solar thermal utilization or variants with very good shell quality and an additional heat recovery ventilation system – are not far from the cost optimum. For the case of a building supplied with district heating the variant solar thermal utilisation even represents the cost optimal variant. However, this finding could be partly due to the overestimation of thermal benefits and energy benefits of solar systems in the monthly balance method of calculating the energy performance certificate.
- Furthermore, regarding those variants in which only the shell quality varies, only small differences in costs occur between the net heating demand lines 14 to 10 for practically all variants under examination, despite all the differences in detail. Only the improvement towards net heating demand line 8 leads to a slight "cost jump". To achieve that level of primary energy performance, the use of a ventilation system becomes interesting in terms of cost.
- The sensitivity analyses which were carried out confirm the overall picture. There are no significant changes in relation to the cost optimality of the different variants which were investigated. Generally speaking, the results prove to be quite stable as far as changes in energy price trends or changes in the discount rate are concerned. The cost optima move only slightly – if at all – the form of the cost curves remains mostly unchanged. The macroeconomic perspective, however, supports the efficient variants more significantly than the private investor’s perspective.
- Several variants featuring major characteristics of nearly-Zero Energy Buildings – very high energy performance; low amount of energy covered to a very significant extent by energy from renewable sources; low CO_2 emissions – are very close to the cost optimum. We could thus derive a summarizing policy recommendation that a further tightening of the current minimum requirements in building regulations could be implemented without effecting substantial overall cost increases over the

life cycle. The increased amount of construction costs would be entirely – or at least for the most part – offset by lower operating costs in the operation period. Moreover, the good economic performance of models with solar thermal energy systems can be regarded as evidence for the mandatory installation of a solar system in multi-family houses.

Acknowledgement

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