smartwin compact

Economic optimum in the regions of Europe

On behalf of pro passivhausfenster GmbH, Oberaudorf, GERMANY

Report

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Content

1 Introduction

Passive Houses are known as both, highly comfortable and affordable. Passive house windows are a key component of this topic. On behalf of pro Passivhausfenster GmbH, Oberaudorf, GERMANY, the Passive house institute has done research based on double, triple and quadruple glazed smartwin compact windows with actual consumer prices of the windows, provided by the pro Passivhausfenster GmbH-member Lorber, AUSTRIA.

The aim of the research is to state, which of the smartwin compact variants should be used in terms of affordability and efficiency in which areas of Europe.

2 Methodology

The data basis and methodology for the following considerations were first applied in [Schnieders et.al. 2011][1] for defining an economically optimum new construction in any chosen climate. The methodology was refined for the analyses documented here and adapted to an additional building, which is a retrofit in a shaded inner city location. On account of the current task, these analyses are largely limited to Europe. In order to help the reader understand the reasons behind this, relevant parts of the text from [Schnieders et.al. 2011] have been reproduced or adopted with slight changes below.

[1] Schnieders, Feist, Krick, Schulz, Rongen et.al.: Passive Houses for different climate zones. Passivhaus Institut, Darmstadt, November 2011.

2.1 Climate data

In order to be able to generate a set of climate data for any point on the surface of the Earth, it is important to obtain the corresponding data at low cost and little effort from a single source. Satellite data from NASA, which is continually available via the EOSWEB interface ([NASA 2009][2]) free of charge and have been processed by the Passive House Institute, are ideal for this purpose.

This data has a spatial resolution of 1 degree, which equates to a distance of up to 111 km. We use 1289 data sets for the areas of land in Europe which are located west of 35° East.

The spatial resolution of the data is not adequate everywhere. Systematic errors can happen particularly in mountainous regions such as the Alps, where the climate can change drastically within the distance of a few kilometres. The climate also changes radically near coasts within the space of a single grid cell.

2.2 Methodology for calculating economic feasibility

If buildings and components are optimised from an economic point of view with reference to their energy demand for heating and cooling, then the necessary extra investment should be considered in relation to the saved energy costs. The most appropriate method for this is that which is known as the 'net present value' method, where each expenditure or income within the life cycle of the building is discounted to the beginning of the period under consideration using the chosen capital interest rate. This takes into account the fact that because of the interest due on the capital, costs which are incurred at a later point in time (here: energy costs) are weighted as being less than the costs which arise at the beginning of the period under consideration (here: investment for construction). More information about this method can be found for example in [Kah 2008][3], [Feist 1997][4], [Feist 2005][5] and [Feist 2013][6].

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[2] http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi, 5.10.0

[3] Kah, Oliver, Wolfgang Feist, Rainer Pfluger, Jürgen Schnieders, Berthold Kaufmann, Tanja Schulz, Zeno Bastian: Bewertung energetischer Anforderungen im Lichte steigender Energiepreise für die EnEV und die KfW-Förderung. Passivhaus Institut, Darmstadt 2008.

[4] Feist, Wolfgang (Hrsg.): Arbeitskreis kostengünstige Passivhäuser, Protokollband Nr. 11, Kostengünstige Passivhäuser, Darmstadt, Passivhaus Institut, Dezember 1997

[5] Feist, Wolfgang (Hrsg.): Arbeitskreis kostengünstige Passivhäuser, Protokollband Nr. 29, Hochwärmegedämmte Dachkonstruktionen, Darmstadt, Passivhaus Institut, Juni 2005

[6] Feist, Wolfgang (Ed.): Ökonomische Bewertung von Energieeffizienzmaßnahmen, Protokollband Nr. 42 des Arbeitskreises kostengünstige Passivhäuser. Passivhaus Institut, Darmstadt 2013

Since the cost of products for construction, labour and energy varies greatly in different countries in Europe, such considerations can only serve as a guideline. Research on energy and construction costs for the affected countries was far beyond the scope of the present study in any case; other optimums may result in individual cases and at current prices.

Besides the window (see chapter 3), the chosen cost estimates are based on the assessment by the authors with reference to average prices throughout the period under consideration. Economies of scale due to the higher number of items, also for products which were exotic up till now, have already been priced in.

2.3 Example buildings

The energy demand for the variants of two sample buildings as described below were determined for each location using the Passive House Planning Package [PHPP 2007][7].

The calculations were first carried out in accordance with [Schnieders et.al. 2011] on the basis of the geometry and orientation of the end-of-terrace house in Darmstadt-Kranichstein (Germany), which was built to the Passive House Standard. The building faces directly south and is moderately shaded; most of the windows are on the south side (30 m² south-facing windows with a living area of 156 m²). Details of this building are provided in the sample file in [PHPP 2007]. The new construction situation was assumed for this building in which any type of e.g. shading and glazing can be chosen, and the heating or cooling system respectively depends on the building characteristics. This building is identified below as **Type I**, see Figure 1.

Obviously, the described new construction situation is atypical for the modernisation of preserved historic buildings. In spite of this, the results are valuable for the present task since the sensitivity of the results and any specific features of the modernisation become clear in comparison with the calculations described below for preserved historic buildings.

In order to cover a wide range of building-types and situations, an existing but retrofitted building in a city location was considered in a second simulation. This is an east-west oriented triple storey Wilhelminian style house as part of a row of buildings in Limburgstraße in Ludwigshafen (see [Schnieders 2005][8]). Inevitably, the results

[7] Feist, Wolfgang (Hrsg.): Passivhaus Projektierungs Paket 2007, Anforderungen an qualitätsgeprüfte Passivhäuser. Darmstadt, Passivhaus Institut, 2007. Englisch: Feist, Wolfgang (Ed): Passive House Planning Package 2007, Specifications for Quality Approved Passive Houses, Darmstadt, Passivhaus Institut, December 2007

[8] Schnieders, Jürgen: Innendämmung – Potenziale und Grenzen. In: Faktor 4 auch bei

obtained for this were completely different on account of the different geometry and the decreased available solar radiation. Apart from this, unavoidable thermal bridges remain after the modernisation. These were taken into account as an overall value. This represents the building **Type II**.

Type I: Passive House Kranichstein:
New building, south oriented

Type II: Retrofit in a City:
East-West oriented, with external insulation

Figure 1: Buildings used for the simulation

2.4 Boundary conditions for the economic feasibility calculation

The boundary conditions summarised in Table 1 to **Fehler! Verweisquelle konnte nicht gefunden werden.** were used for the calculations. All prices are retail prices including VAT. The present value of the energy service "comfortable temperature-controlled interior space" is obtained from the invested costs and the capitalised energy costs over the 40-year period under consideration. The house is cost-optimised if this value is minimal.

For glazing and windows, please see Figure 2.

Four ventilation strategies were examined for each of these window and glazing types:

a) Exhaust air system without HRV/ERV, with night-time ventilation via tilted windows across several storeys (n = 0.46 h^{-1} for a temperature difference of 1 K)
b) Exhaust air system without HRV/ERV, without night-time ventilation
c) Supply and extract air system with 90 % HRV, with night-time ventilation as above

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sensiblen Altbauten: Passivhauskomponenten + Innendämmung; Protokollband Nr. 32 des Arbeitskreises kostengünstige Passivhäuser Phase III; Passivhaus Institut; Darmstadt 2005.

d) Supply and extract air system with HRV as above and 80 % ERV, without night-time ventilation

The economically optimum U-values of the opaque exterior building components were determined for the best ventilation strategy in terms of cost. Apart from this, an economically optimal level of airtightness was specified for the new construction case Type I, whereby an overall amount of € 5 per square metre of living area was set for improvement from n_{50} = 0.6 h^{-1} to 0.35 h^{-1} and from 0.35 h^{-1} to 0.25 h^{-1}. In principle, values worse than 0.6 h^{-1} were not permitted here in order to guarantee faultless functioning of the ventilation system, structural integrity etc. Better values were interpolated or extrapolated using a hyperbola. The n_{50} value was always 1.0 h^{-1} for the refurbishment case Type II. The economic optimums of U-values and airtightness depend on the length of the heating or cooling periods and thus on the mechanical systems of the building and the quality of windows used, therefore they must be redefined for each variant.

The first economic optimum is obtained in this way. If passive cooling is not sufficient for the thus calculated building, then shading equipment in accordance with **Fehler! Verweisquelle konnte nicht gefunden werden.** is additionally taken into account in the comparison[9].

Finally, a search was made for a functioning Passive House for the new construction variant Type I. If the heating load or the sensible cooling load of the building which was optimised as previously described was higher than 10 W/m², then thermal protection was improved for the cases with supply air and extract air systems in such a way that both these limits were undercut. In this case a discount was made for a simplified building services system (supply air heating or cooling) according to Table 2. This procedure was not carried out for Type II, so this type shows the economic optimum without heating via the ventilation system.

[9] For Type II, it was assumed all throughout that there is temporary shading on the outside. This is generally the case in existing buildings in Southern European climates, for colder climates shading is less relevant in any case.

Table 1: Boundary conditions of the economic analysis

Real interest[1]	2.5 %
Usage period of exterior building components	40 years
Price of additional insulation for wall and basement ceiling[2], λ = 0.035 W/(mK)	€ 1/cm/m²
Price of additional insulation for roof	€ 0.50/cm/m²
Price of additional wall insulation in case of interior insulation[3]	€ 7/cm/m²
Average price of final energy[4]	9.2 cents/kWh
Efficiency factor of heat generator	92 %

1 This is a typical value for the mortgage interest rate, taking into account the rate of inflation (see [Feist 2013]).

2 The basement ceiling can in principle be insulated at a low price similar to that for the roof; however, there is often insufficient space available, so one would have to use materials with a smaller thermal conductivity, which costs even more than exterior wall insulation. With the value set here, we have adopted the middle course between the two.

3 A loss of living area has been priced in for interior insulation. With an overall price of € 1500 per m² living area and a room height of 2.50 m, this gives an additional square meter price of € 6 per centimetre of thermal insulation. In principle, the approach for loss of living area would only be justified from the point when the interior surface temperature allows the placing of furniture next to the exterior wall, otherwise a gain in living area would have to be assumed as a matter of principle. However, like the general increase in residential quality due to increased comfort, this has not been taken into account here so that the ascertained insulation thicknesses are rather too low.

4 The average real price during the period under consideration, inc. taxes and duties. If local energy prices are significantly lower, this is either due to subventions, or the locally produced energy could have been sold more profitably on the world market. In such cases, this has to do with a macroeconomic rather than a microeconomic analysis, but price adjustments during the usage period of a building are particularly likely in these cases. Further increases in energy prices during the period under consideration have not been included since in the long term, the substitution of increasingly scarce fossil fuels with renewable energy sources for a price slightly higher than the current price level is likely. Useful cooling energy for cooling and dehumidification is included with the same price as that for heating energy.

- **Table 2: Cost assumptions for mechanical services in € per square metre living area**

	Costs [€/m²]
Extract air or supply air system	15
Supply air and extract air system with HRV	40
Additional costs for ERV	5
Heat or cold air distribution, in case heating or cooling load is greater than 10 W/m²	20

3 Window data and prices

Drawings of the window profiles used and installation situation, the thermal properties of the materials and glazing used as well as the consumer prices of the windows were provided by the pro Passivhausfenster GmbH member Lorber, see Figure 2. It can be seen, that the prices for Type I, Kranichstein are much lower, than for Type II, Limburger (the double glazed windows for Limburger are more expensive as the quadruples for Kranichstein). This is because Kranichstein has bigger windows with less glass divisions. So bear in mind, that the proportions and the style of the windows might have a higher influence on the price, than the thermal properties!

LORBER FENSTERBAU

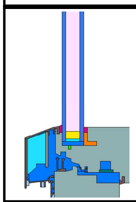
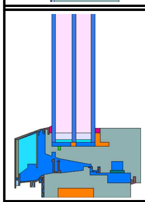
Window		Ug W/(m²K)	g -	Kranichstein €/m²	Limburger €/m²
	2WS compact	1,10	0,63	431	554
	3WS compact	0,53	0,53	454	593
	3WS+ compact	0,61	0,6	461	600
	4WS compact	0,35	0,42	536	672
	4WS+ compact	0,46	0,59		

Figure 2: Used windows with the thermal properties of the glazing and prices per square meter.

The thermal data of the window profiles and the installation situations were calculated based on two-dimensional thermal flow analyses by the Passive house Institute, see [Krick 2014][10]. Figure 3 shows the most relevant properties of the considered window frames.

pro passivhausfenster smartwin compact double		Bottom / Unten	Top / Oben	Side / Seitl.	Bottom fixed / Unten fest	Top fixed / Oben fest	Side fixed / Seitl. fest
Temperaturfactor $f_{Rsi=0,25m^2K/W}$ / Temperaturfaktor $f_{Rsi=0,25m^2K/W}$		0,59	0,63	0,63	0,61	0,63	0,63
Frame width b_f / Rahmenbreite	mm	0,076	0,067	0,067	0,076	0,067	0,067
U-value frame U_f / Rahmen-U-Wert	W/(m²K)	1,21	0,84	0,84	0,96	0,67	0,67
Ψ-glass edge Ψ_g / Glasrand-Ψ-Wert	W/(mK)	0,032	0,032	0,032	0,033	0,035	0,035
Ψ_{opaque} / Ψ_{opak}	W/(mK)	0,101			0,089		
Passiv House effiziency class / Passivhaus Effizienzklasse		phA			phA		
U_w @U_g = 0,70 W/(m²K)	W/(m²K)	1,155			1,122		

pro Passivhausfenster smartwin compact triple		Bottom / Unten	Top / Oben	Side / Seitl.	Bottom fixed / Unten fest	Top fixed / Oben fest	Side fixed / Seitl. fest
Temperaturfactor $f_{Rsi=0,25m^2K/W}$ / Temperaturfaktor $f_{Rsi=0,25m^2K/W}$		0,72	0,74	0,74	0,74	0,76	0,76
Frame width b_f / Rahmenbreite	mm	0,076	0,067	0,067	0,076	0,067	0,067
U-value frame U_f / Rahmen-U-Wert	W/(m²K)	0,94	0,70	0,70	0,70	0,53	0,53
Ψ-glass edge Ψ_g / Glasrand-Ψ-Wert	W/(mK)	0,020	0,021	0,021	0,020	0,021	0,021
Ψ_{opaque} / Ψ_{opak}	W/(mK)	0,076			0,062		
Passiv House effiziency class / Passivhaus Effizienzklasse		phA			phA+		
U_w @U_g = 0,70 W/(m²K)	W/(m²K)	0,768			0,730		

Figure 3: Most relevant properties of smartwin compact double and triple.

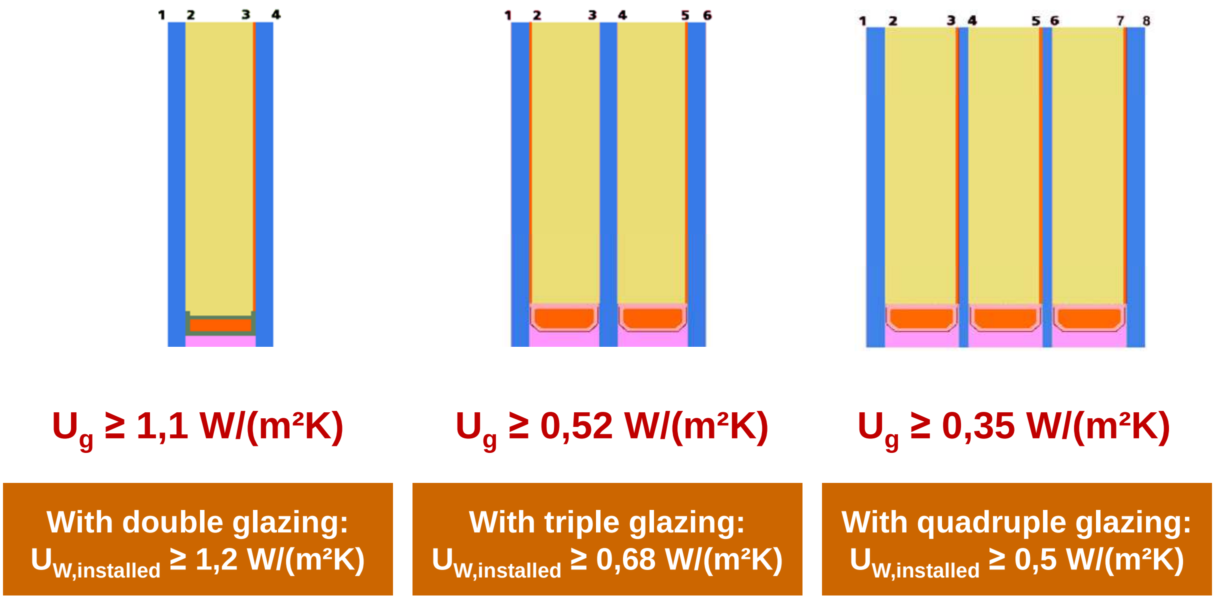


Figure 4: Achievable U-values of the installed window.

4 Catching the comfort criterion

If a certain level of thermal insulation is reached, high thermal comfort can be achieved by avoiding unpleasant heat radiation losses and cold down drafts. The Passive house institute has figured out, that this level is reached, when the temperature difference between the inner surface of the building and the operative room temperature is less than 4.2 K (Passive House

[10] Krick, Benjamin: Certification report for smartwin compact, PHI Darmstadt, 2014

comfort criterion, see for instance [Feist 1998][11]). From that, the required minimum U-value of the thermal envelope can be calculated depending on the design outside temperature. For design outside temperature, the average temperature of the coldest day in a reference year is taken into account.

Figure 4 shows the achievable U-values of the installed window with double, triple and quadruple glazing. By putting together this U-values, the local design outside temperature and the comfort criterion, can be defined where which glazing should be used all over Europe, see Figure 5: The map shows, that in most parts of Europe triple glazing is to be used. In the north and east, quadruple glazing should be chosen and only in Mediterranean areas and in regions directly influenced by the Gulf Stream, double glazing might be used.

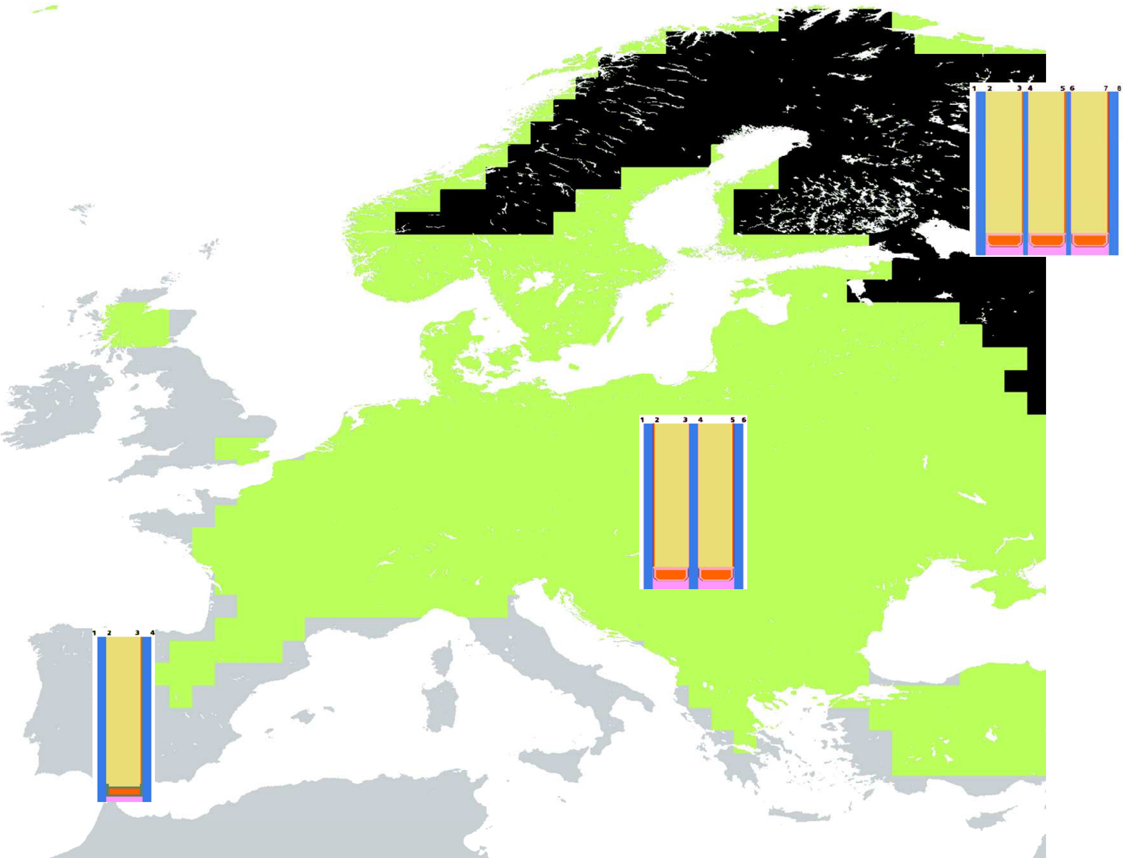


Figure 5: Glazing to be used in Europe for catching the comfort criterion.

5 Economic optimum: German and Austrian price level

5.1 Functional passive house

The functional passive house criterion means, that the possibility must be given to heat (or cool) the building by only heating up (or cooling down) the, for hygienically needed reasons supply air. This is possible, if the heating load is not higher than 10W/m² (see [Feist 2007][12]).

[11] Feist, Wolfgang; Fenster: Schlüsselfunktion für das Passivhaus-Konzept, 14. Arbeitskreis kostengünstige Passivhäuser, Passivhaus Institut Darmstadt; Dezember 1998

[12] Feist, Wolfgang: Passivhäuser in der Praxis. In: Fouad, Nabil (Ed.): Bauphysikkalender

Figure 6 shows, that the functional passive house is the optimum at any location in Europe for type II, while this is not the case for type I in Scandinavia, north-east Europe and parts of Africa. This is because of the big windows of type I. In Africa, there are too much solar gains, so the cooling load gets too high. The windows are, compared to the opaque envelope the weak point of the building, the losses are so high that heating by supply air is not the economic optimum in north and north-east Europe.

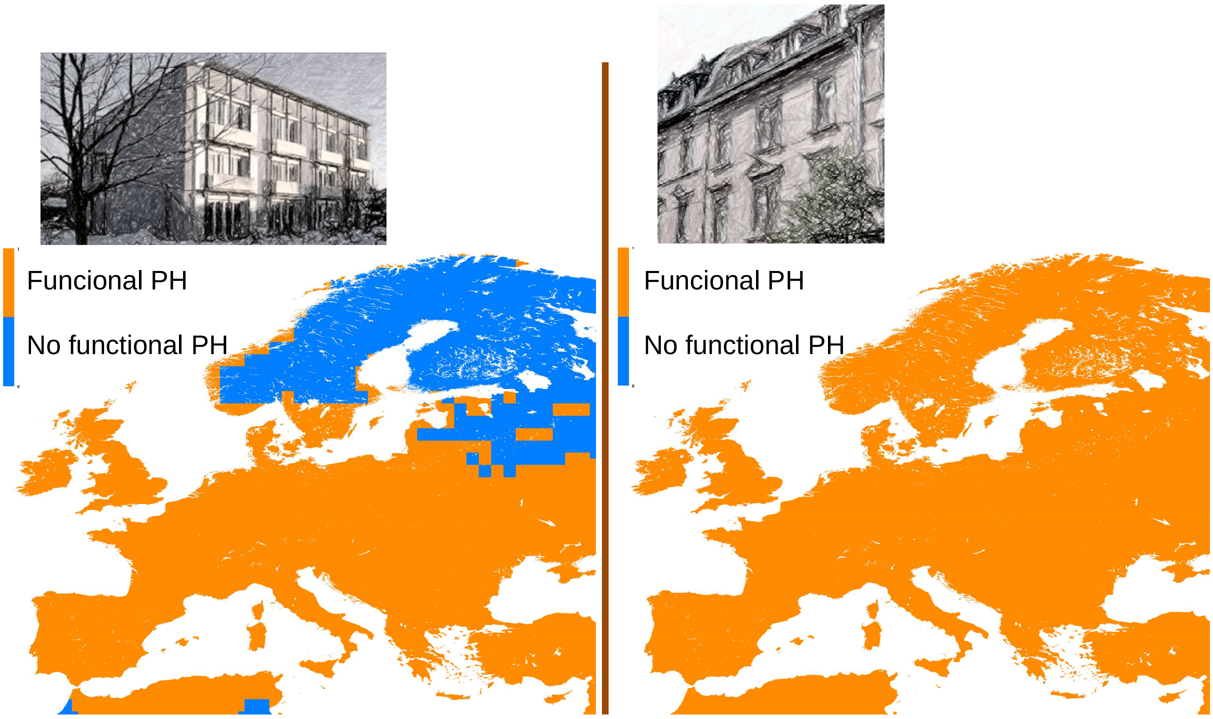


Figure 6: Functional passive house and economic optimum.

5.2 Heating energy demand

A higher heating demand must be calculated for existing buildings like type II in contrast with new constructions like type I, if only because of the thermal bridges. However, the differences are moderate: in a new construction for Type I, 15 kWh/(m²a) are seldom exceeded. The heating demand of the cost optimal modernised Type II with exterior insulation is still below 10 in the Mediterranean region. In Germany this is ca. 15 and in Scandinavia this is ca. 30 kWh/(m²a); it is barely above the result for the new construction in Southern Europe and in Scandinavia between 10 and 15 kWh/(m²a) above this, see Figure 7.

2007; Ernst&Sohn, Berlin 2007

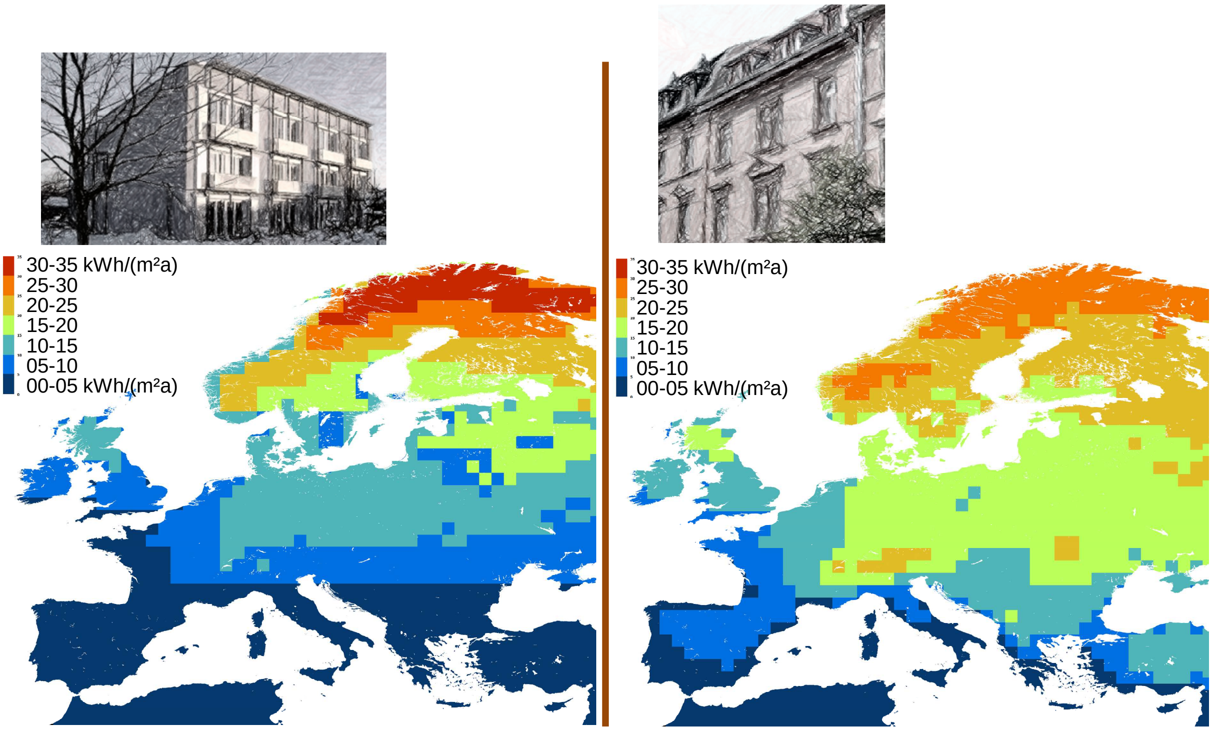


Figure 7: Heating demand of the cost optimized buildings.

5.3 Primary energy demand

The primary energy demand includes the demands of heating, cooling, auxiliary, domestic hot water and household electricity rated by primary energy factors. According to the heating demand, **Fehler! Verweisquelle konnte nicht gefunden werden.** shows that the PE-demand is a bit higher for type II. Especially on the map for type I it can be seen that, due to cooling, the PE demand rises again, going to the very south of Europe and Africa.

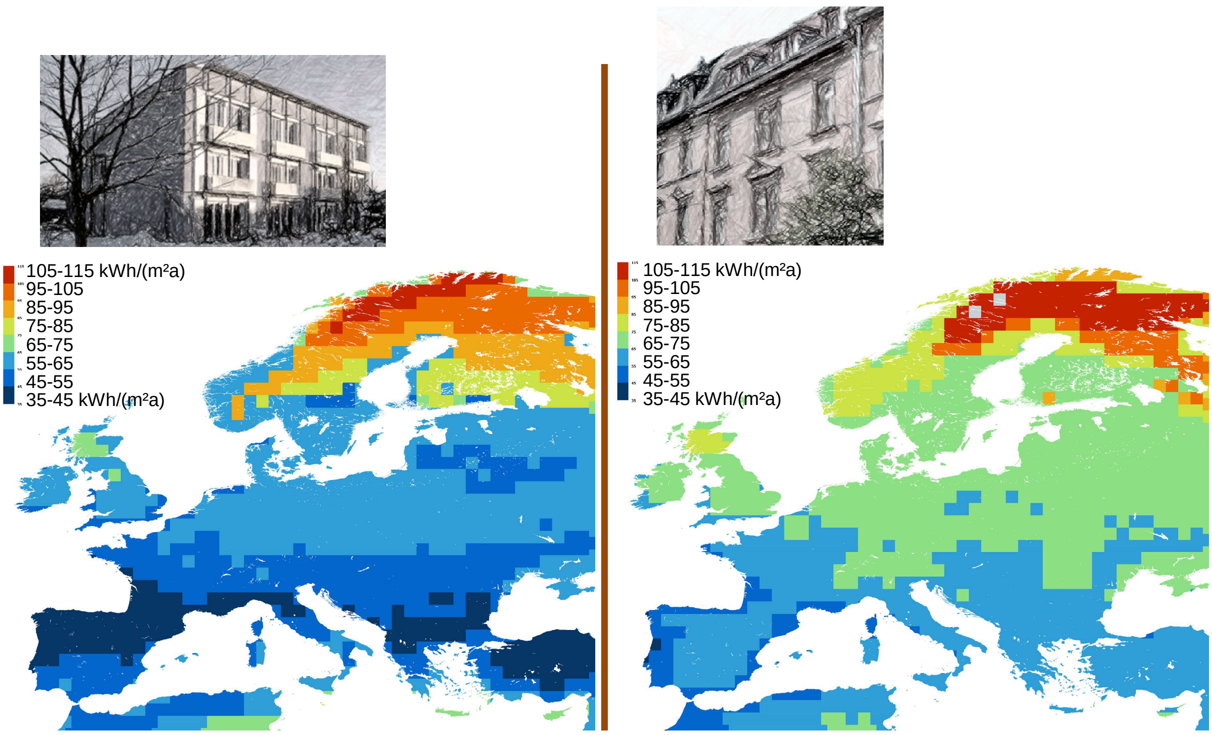


Figure 8: Functional passive house and economic optimum.

5.4 Windows and glazing

Figure 9 finally shows the types of windows and glazing of the economic optimized building. For both types, the u-value optimized triple glazing is clearly dominant. While for type I, quadruple glazing is not an option worth considering, this is different for type II in Scandinavia. The use of double glazing is negligible. Type II cannot achieve much solar gains because of the east-west orientation and the shading by neighbouring buildings. Because of this, the U_g-value (which is best for quadruple glazing) matters more than the g-value, which is better for triple, than for quadruple glazing, see Figure 2. On the map of type I it can be seen, that in very south regions the u-value optimized glazing is the better option. This is due to its lower g-value which is helping to reduce cooling. Please note, that in northern Europe, quadruple glazing should be used because of comfort considerations, even though it is not the economic optimum.

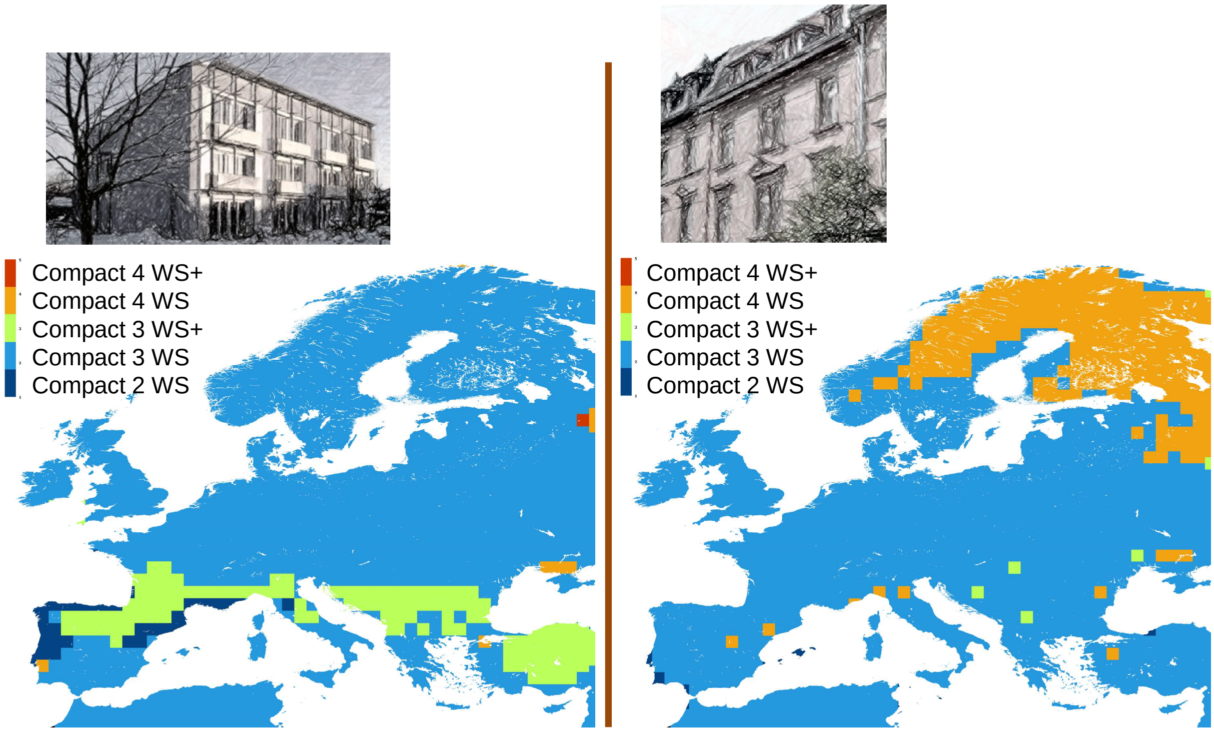


Figure 9: Window types of the economic optimized buildings.

5.5 Windows and glazing with future glass prices

At present time, quadruple glazing is extraordinarily expensive, see Figure 10. This was also the case for triple glazing compared to double glazing, some years back. If quadruple glazing becomes more common, lower prices might result. This could mean a much higher proportion of quadruple glazing for both types all over Europe, see **Figure 11**. Especially for buildings like type two, quadruple glazing might be the more economical solution in wide parts of central Europe. Even today quadruple glazing could be a sensible option under special circumstances, for instance, if only small wall insulation can be used because of legal rules or historic issues.

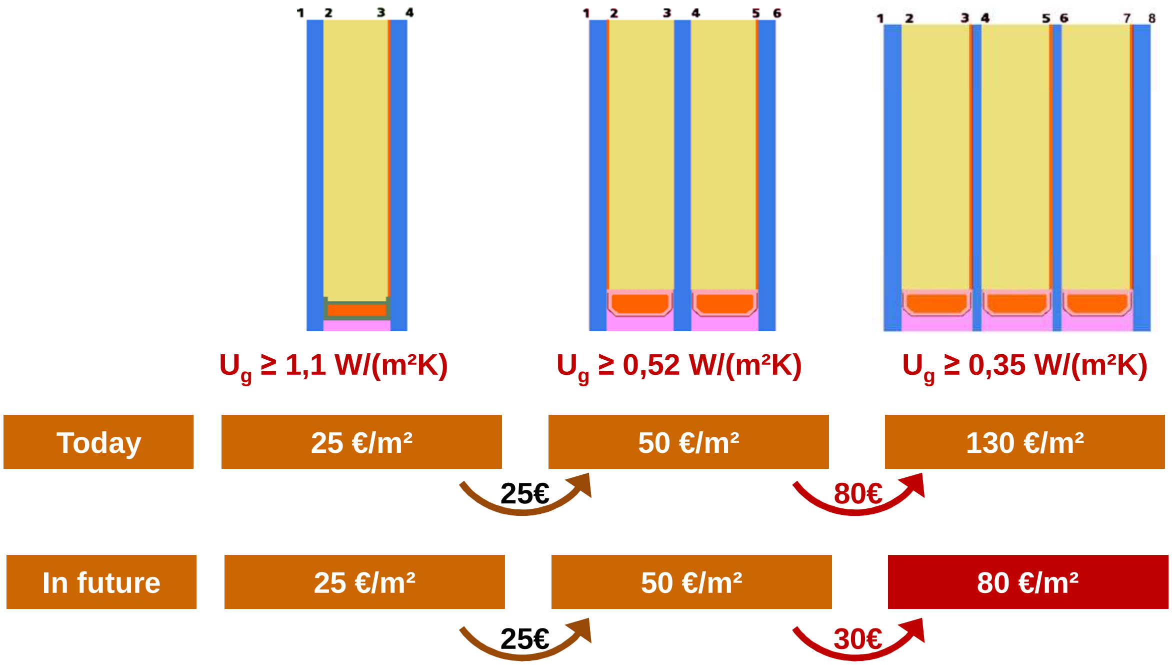


Figure 10: Present and predicted future glass prices.

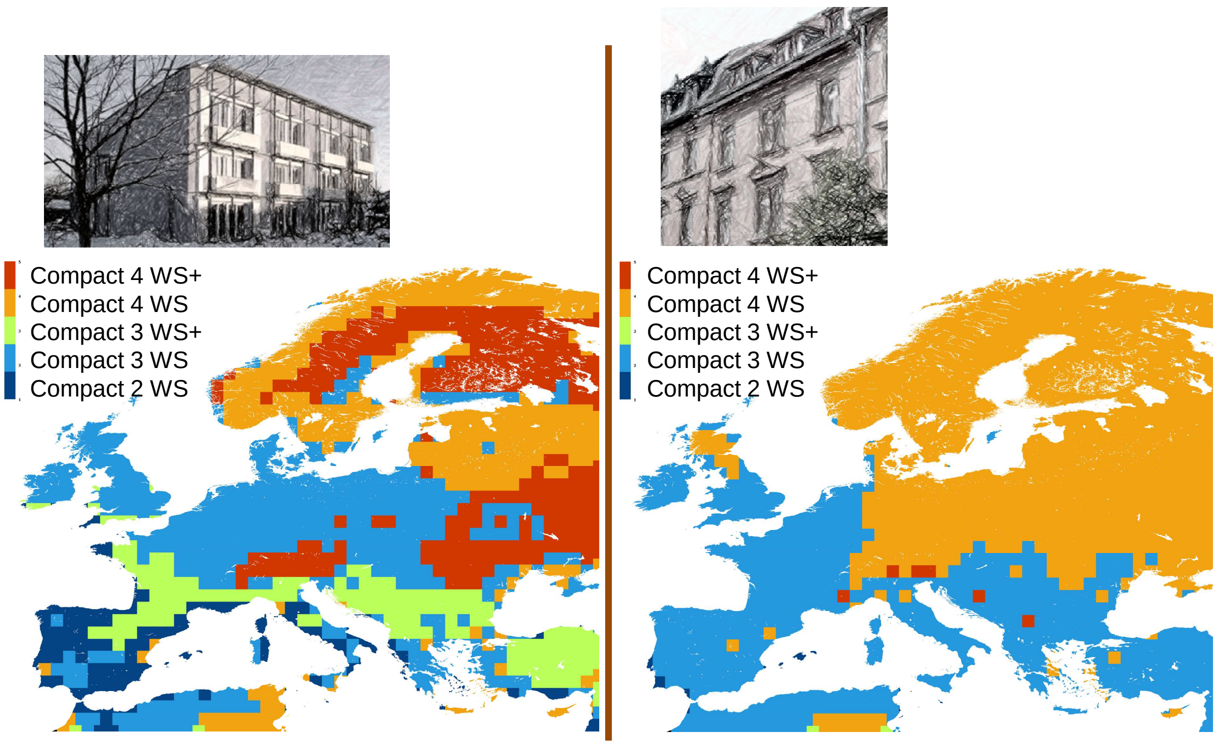
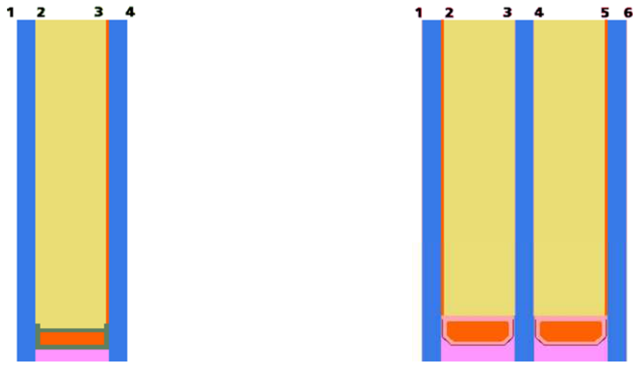


Figure 11: Types of windows and glazing in the economic optimized building under based on possible future price levels or quadruple glazing.

6 Economic optimum: Irish and UK price level

Today, glazing prices are varying all over Europe. Due to this, the calculations were done again on Irish/UK-price levels in cooperation with the pro Passivhausfenster partner Eco Homes, Cork, Ireland. Figure 12 shows the prices used and thermal properties, Figure 13 shows the results of this variant of the study in comparison to the version with German prices.



In coopera-
tion with

PRO PASSIVHAUSFENSTER

ECO Timber Frame

U_g: 1.20 W/(m²K)
g: 0.72
557 €/m² (452 GBP)

U_g: 0.50 W/(m²K)
g: 0.43
608 €/m² (494 GBP)

U_g: 0.57 W/(m²K)
g: 0.64
590 €/m² (479 GBP)

Figure 12: Prices and thermal data for the Irish variant of the study.

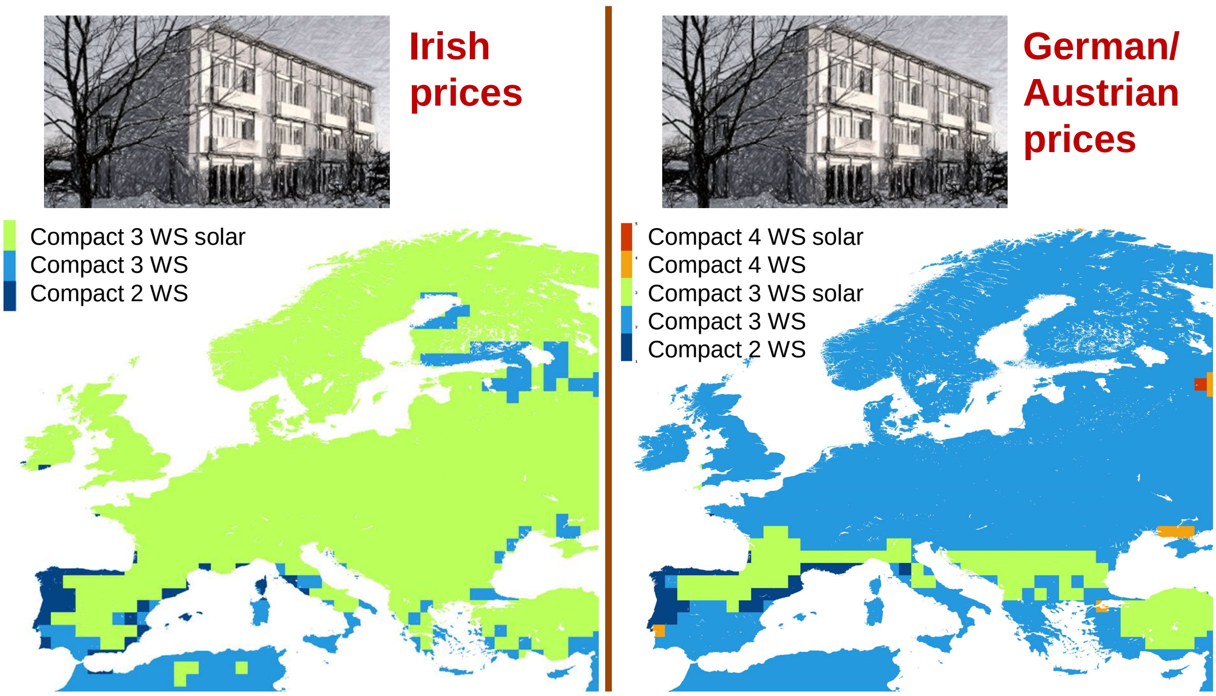


Figure 13: Windows and glazing under consideration of Irish/UK-prices.

The solar optimized glazing is less expensive here, than the U-value optimized variant. So the solar optimized triple glazing is dominant.