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Economic and Energy Efficiency of Building Modernizations

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Kurzfassung [dt.]: Dieser Beitrag untersucht die Wirtschaftlichkeit und Umweltwirkung energetischer Sanierungen bestehender Gebäude mit Schwerpunkt auf der Modernisierung der Gebäudehülle. Anhand von 140 Maßnahmen in 57 Gebäuden werden Lebenszykluskosten und Energieeinsparungen verglichen. Die Ergebnisse zeigen, dass die Dämmung von Außenwänden den höchsten wirtschaftlichen Nutzen bietet, gefolgt von Dach- und Fenstersanierungen, während Dachfenster weniger rentabel sind. Insgesamt könnten über 250 Mio. kWh Heizenergie eingespart und mehr als 80.000 t CO_2 vermieden werden. Die Arbeit liefert ein evidenzbasiertes Bewertungsmodell zur Priorisierung von Sanierungsmaßnahmen und zur gezielten Förderung klimarelevanter, aber weniger rentabler Komponenten.

Abstract [en]: This contribution assesses the economic and environmental performance of energy-efficiency upgrades in existing buildings, focusing on thermal envelope modernization. Drawing on data from 140 retrofit measures across 57 buildings, it compares lifecycle costs and energy savings under varied component conditions. Results show that exterior wall insulation delivers the highest return on investment, followed by roof insulation and window replacements, while skylight upgrades are least cost-effective. The analyzed measures could save over 250 million kWh and prevent 80,000 tonnes of CO_2. The study introduces an evidence-based framework for prioritizing retrofit investments and guiding strategic funding for building decarbonization

Schlagwörter (dt.): Energieeffizienz; Gebäudesanierung; Nachhaltigkeit; Lebenszykluskosten; Kosten-Nutzen-Analyse

Key Words (en.): Energy Efficiency, Building Retrofit, Sustainability, Life Cycle Costs, Cost-Benefit Analysis

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Introduction

According to meteorological records, 2024 was the first year in which the average temperature rise exceeded 1.5°C (World Meterological Organization, 2025). Whether this is an exception or whether this mark has become permanently unattainable will become clear in the coming years. This would mean that the central goal of the 2015 Paris Climate Agreement has already been missed. With every further rise in temperature, the dangers to humans, animals, and ecosystems as a whole increase.

According to the European Union, indirect and direct emissions from buildings account for around 34% of total energy-related emissions (European Environment Agency, 2024). The share of emissions produced by buildings according to the Climate Protection Act (Klimaschutzgesetz) is estimated at 13% of total emissions (Lützkendorf, 2021). However, in order to determine the total amount of building-related emissions, it is not sufficient to consider the building sector alone. Significant portions of the energy sector should be included into the calculation of building-related emissions, especially the use of district heating and electricity, specifically household electricity and electricity for heating and cooling. The logistics of construction also generate the need to take emissions of the transportation sector into account. The manufacturing of building materials utilizes mainly fossil fuels, which leads to the need to include the industry sector. Waste management in turn disposes of building materials partially by incineration to be used again as district heating or electricity, requiring that to also be included in the consideration of emissions generated by buildings.

This insight shows that the construction, operation, and demolition of buildings have a significant impact on the overall greenhouse gas balance. A study by the German Federal Institute for Research on Building, Urban Planning, and Regional Development concludes that, in 2014, around 40% of greenhouse gas emissions in Germany were attributable to direct and indirect emissions from the manufacturing of construction materials as well as the construction, modernization and use of buildings. Approximately 10% of these emissions were additionally generated by suppliers abroad (Bundesinstitut für Bau-, Stadt- und Raumforschung, 2020).

In Germany, efficiency targets have been continuously updated, so that modern new buildings now require only a fraction of the heat needed by older buildings. This has also led to an increase in construction costs, partially caused by the more extensive insulation measures and their downstream effects. However, life cycle based energy requirements, greenhouse gas emissions and costs of buildings were not considered.

This circumstance must be critically examined, especially since increasing insulation measures results in an approximate linear increase in construction and demolition costs as well as building material-related emissions but have a degressive effect on energy demand during use.

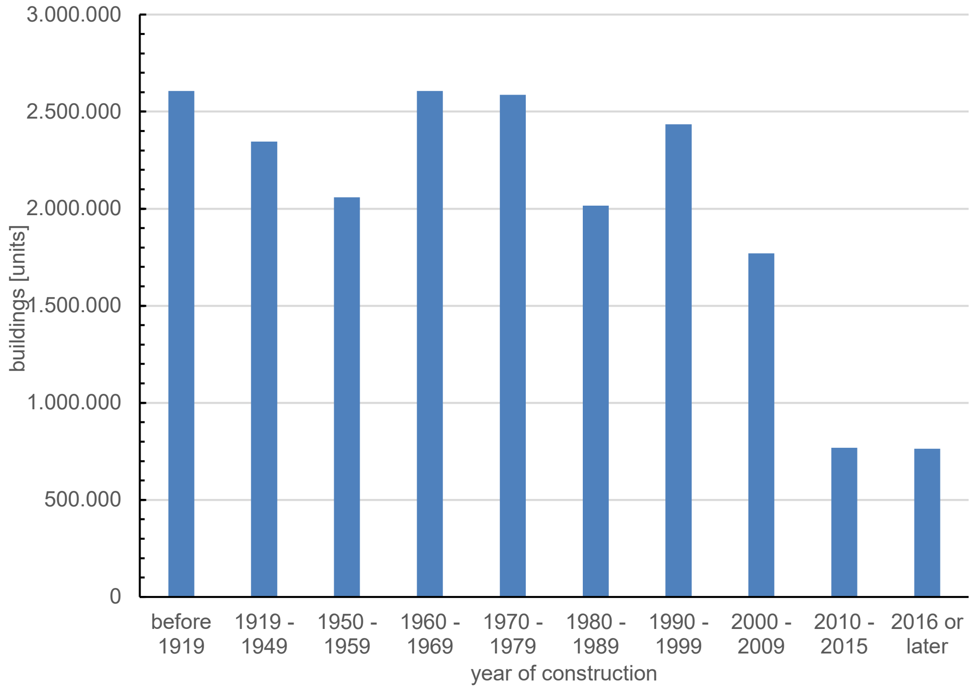


Figure 1: Age distribution of the building stock in Germany (Statistische Ämter des Bundes und der Länder, 2024)

Figure 1 shows residential and mixed-use buildings by year of construction. According to data from the German Federal Environment Agency, more than a third of the building stock is completely untouched in terms of energy efficiency. (Umweltbundesamt, 2024) Overall, around one percent of buildings is comprehensively modernized each year in terms of energy efficiency, which significantly jeopardizes the climate targets for the building sector. (Cajias and Piazolo, 2013) In line with this, the German building sector has once again failed to meet its 2023 emission targets. As a result, the German Building Energy Act (Gebäudeenergiegesetz) has to be significantly tightened in order to bring the sector into compliance with German and European legislation (Fischedick, 2025).

Various strategies to reduce emissions stemming from buildings have been examined like the effects of the behaviors of buildings occupants (Abbas et al., 2025), encouraging energy-saving strategies mitigating high energy consumption (Khafiso et al., 2025) or wider use of smart home thermostats (Jiang et al. 2024). This contribution focuses on the environmental effects of energy-efficiency modernization of buildings.

Methodology

General

The Construction Cost Information Center of German Chambers of Architects (BKI) maintains databases on new construction, renovation, and modernization measures carried out on existing buildings. These are adjusted quarterly for inflation using the construction cost index published by the BKI (2025). However, the delayed publication of the index results in a certain lag in the cost data. It is therefore to be expected that the actual results will tend to be slightly higher than the calculated costs.

Energy-efficient modernization measures can be categorized according to the building components affected. This approach is more accessible because often individual component, rather than complete modernizations are carried out. Furthermore, it can be assumed that different building components will yield different results in life cycle costing (LCC) analyses for reasons related to their design and materials. The components in question, listed from top to bottom, are:

- Steep, flat-sloped and flat roofs
- Top floor ceilings to unheated attic spaces
- Exterior walls
- Windows and exterior doors
- Ceilings to unheated basements or cellars
- Floor slabs or base plates to the ground

Since the available data does not include any priced bills of quantities, the cost groups of the German national organization for standardization DIN 276:2018 in the third level can be used with the specified quantities, measures, and costs (DIN, 2018).

The following terms are established for the investigations:

Maintenance: minor (usually routine) construction measures to maintain the quality and building fabric

Overhaul/Repair: construction measures to maintain the current quality

Modernization: major construction measures to increase quality

Discussion of data

By referring to the component areas, only transmission heat losses are considered. As a result, the reduction of ventilation heat losses through mechanical or window ventilation and infiltration, as well as lower losses via thermal bridges, are not considered. The savings are therefore conservative estimates.

As the individual measures are categorized according to DIN 276 cost groups, some work is considered that is not related to the actual area-related energy measures. Measures such as the insulation of roller shutter boxes or the replacement of window sills can also be carried out, which have an energy-related effect but are not included in the result for methodological reason. Furthermore, the cost data used was adjusted by BKI (2025) to the cost status Q3 2024.

Energy efficiency is rarely the sole focus in existing building modernizations; improvements to comfort and layout often involve structural changes, complicating direct comparisons. Therefore, the building’s later state—including thermal envelope components—is used as a reference. However, this approach works best for minor changes. Larger renovations and extensions increasingly introduce disruptive factors into the calculation and subsequent comparison due to the cost data being broken down into cost groups. In the case of the former, however, the influence is clearly dependent on the cost groups.

Furthermore, the basement ceiling and the top floor ceiling are particularly difficult to evaluate. Since both are classified as “cost group 350 – ceilings” within the meaning of DIN 276 and, in addition, any structural changes to intermediate ceilings fall into the same cost groups, these are only suitable for consideration in the evaluation in a few cases (DIN, 2018).

At the same time, the costs of work purchased and invoiced by the meter or piece, such as windowsills, edge insulation strips, and baseboards, are also considered. Costs for scaffolding and construction site equipment, as well as ancillary construction and financing costs, are not considered.

Calculation of transmission heat losses

The calculation of u-values (thermal transmittance) is carried out in accordance with ISO 6946:2017:

$$U = \frac{1}{R_T} \tag{1}$$

The thermal resistance R_T is:

$$R_T = R_{si} + \sum_{i=0}^{i} \frac{d_i}{\lambda_i} + R_{se} \tag{2}$$

R_{si}: internal surface (thermal) resistance

R_{se}: external surface (thermal) resistance

The measure-specific U-value of the new envelope component is:

$$U_{new} = \frac{1}{R_{T,old} + \Delta R} \tag{3}$$

Where ΔR results from the difference between the sum of the thickness-to-conductivity ratios of the materials in the new and those of the removed constructions.

Due to the different extent of data depending on the building, the following prioritization is applied to determine the U-values after modernization:

- Specified thermal transmittance values (U-values)
- Data on constructions and building materials specified in the cost groups
- Data on building materials specified in the building description
- Estimates based on typical constructions according to year of construction in accordance with DIN EN 12831:1-2017

However, because of the mathematical relationship between thermal resistance R, component thickness d, and thermal conductivity λ, the inaccuracies caused by missing documentation of existing constructions have no significant impact on U_{new}. The significantly lower thermal conductivity of insulation materials means that these determine the relevant proportions of the subsequent thermal insulation level. Subsequently substructures and cladding materials play a subordinate role in the result.

Energy performance accounting

A total of 54 buildings were examined, with 143 suitable building component measures implemented across them. The data is available at the third level of the cost calculation in accordance with DIN 276

(DIN, 2018). As most of the buildings examined have combined energy and non-energy measures, the following quality criterion is used to evaluate the individual cost groups:

$$\frac{A_{en}}{A_{KGR}} \geq 0{,}90[-] \tag{4}$$

A_{en}: area of the modernization measure

A_{KGR}: area assigned to the third-level cost group according to DIN 276 (DIN, 2025)

Energy-related building component modernizations are included if they cover at least 90% of the total cost group area; smaller shares and unclear quantities are excluded. Construction costs from 1999–2016 are updated to Q3 2024 prices using the German Federal Statistical Office's index, reflecting recent significant increases in construction and energy costs for more reliable future projections (Statistisches Bundesamt, 2025).

Following VDI 2067, energy demand is estimated via the heating system's full-load equivalent hours, allowing flexibility with available data for economic feasibility (VDI, 2012). Savings are calculated by multiplying the reduction in transmission heat loss by the modernized component area, annual heating degree days (3,622 days for Potsdam and 15°C, 2003–2012) and the expected service life from BKI (2025) statistics. Since VDI 2067 is a guideline, specifically created for economic viability calculations, it offers sufficient flexibility for the underlying data depth (VDI, 2012). The calculation is summarized in the following formula:

$$\Delta Q_{h,WE} = \frac{\Delta U_m * A * HDD * 24 \left[\frac{h}{d}\right] * SL}{1.000 \left[\frac{W}{kW}\right]} \tag{5}$$

$\Delta Q_{h,WE}$: Difference in heat loss through transmission [kWh of heat]

SL: Service life of the component [years]

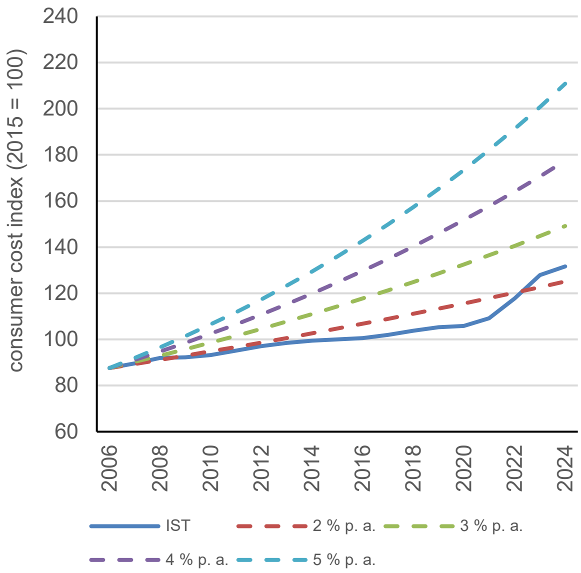
ΔU_m: Difference in the average thermal transmittance U [W/(m²K)]

A: External surface area of the component [m²]

HDD: Heating degree days [d/a], based on the reference location Potsdam, as the arithmetic mean between 2003 and 2012 (here: 3,622 d/a)

For the calculation of the final energy and emissions, the heat energy is calculated using the approximate system expenditure number of 1.3 for a modern gas heating system. This includes losses due to the generation, distribution, storage and transfer of heat.

The energy costs discounted to the present value are used to calculate the energy costs saved. Linear simple regressions can be carried out using the two point clouds for costs and savings depending on the energy quality over the service life of the components.


consumer cost index (2015 = 100)
240
220
200
180
160
140
120
100
80
60
2006
2008
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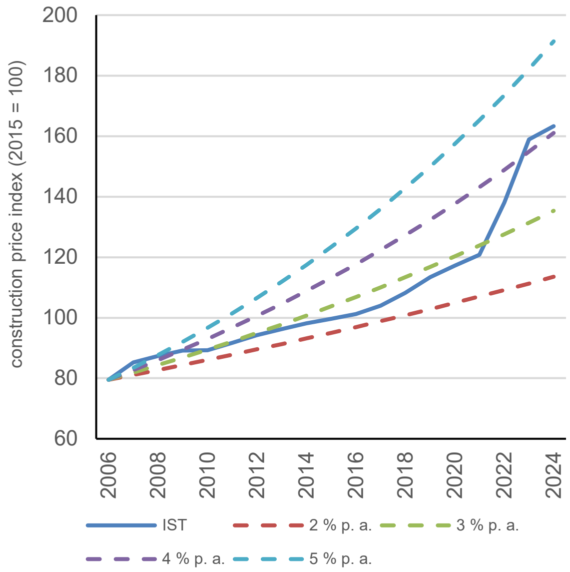
IST
2 % p. a.
3 % p. a.
4 % p. a.
5 % p. a.


construction price index (2015 = 100)
200
180
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2 % p. a.
3 % p. a.
4 % p. a.
5 % p. a.

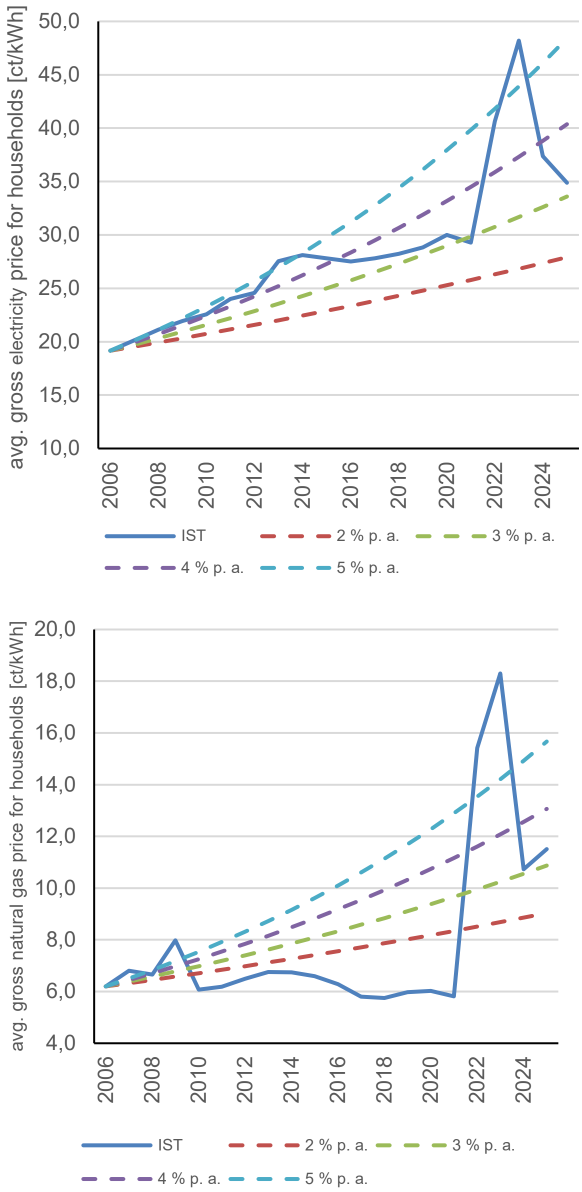


Figure 2: Historic inflation trends regarding consumer costs, construction, electricity and natural gas prices (own illustration, based on Statistisches Bundesamt, 2024, 2025; Verivox, 2025b, 2025a)

The inflation trends regarding consumer costs, construction, electricity, and natural gas prices in the last two decades are shown in Figure 2. The calculation (NPV) of costs and savings by area due to the reduced energy demand is done by the following formula:

$$K_{FE,NPV} = \int_{x=0}^{SL} \left(\left(K_{FE,0} + \frac{(1 + I_{FE})^x}{(1 + I_{CCI})^x} \right) * \ E_{FE,a} \right) dx \qquad (6)$$

$K_{FE,NPV}$: NPV of final energy costs over the service life of the component [€]

$K_{FE,0}$: costs of final energy at the time of modernization per kWh (here Q3 2024)

SL: service life of the component [a]

I_{FE}: inflation rate for final energy (here assumed for natural gas: 3,1% p. a.)

I_{CCI}: inflation rate for consumer costs (here assumed: 2,2% p. a.)

$E_{EE,a}$: annual required final energy for heating (including generation, distribution, storage and transfer losses) [kWh/a]

The actual service life of a component varies widely due to maintenance, environmental exposure, pests, stress, materials, and design quality. Delayed maintenance can accelerate aging in other layers. Maintenance intervals are typically planned to extend or compress component lifespans, enabling multiple layers to be repaired simultaneously.

From a practical standpoint, the building's economic performance generally improves when modernization occurs at or near the damage threshold, i.e., toward the end of a component's service life. Coordinating measures across components or systems can create synergies, reducing overall planning and construction costs. Observing existing buildings also constitutes the consideration of different conditions of components, some of which may be already near of at their end-of-life, while others were repaired of overhauled recently. For the following investigations, the former is considered as the best-case and the latter as the worst-case scenario.

Projection of life-cycle costs for modernizations

The estimation of the measures' life cycle costs is based on the following key assumptions:

1. Service life of a building
    a. The total service life of the building has not changed due to the modernization of the thermal envelope components.
    b. The remaining service life of the structural parts is in every case at least as long as the total service life of the new (modernized) components.
2. The deconstruction costs can be described as a percentage of the new construction costs related to the end of the service life SL using the net present value (NPV) method. Depending on the component, the deconstruction costs are the arithmetic mean of the measures examined:

	Thermal envelope component	Deconstruction costs f_DC,0	Expected service life	Deconstruction costs end-of-service life f_DC,SL	Mean Insulation thickness [m TCR 035]	Replacement or repair costs f_rep
a)	Sole slabs, base plates	12.9%	50 a	31.0%	0.150	80%
b)	Ceilings to unheated basements	-	-	-	-	-
c)	Exterior walls	27.2%	40 a	54.6%	0.146	50%
d)	Windows	9.4%	40 a	18.8%	-	63%
e)	Ceilings to unheated attics	-	-	-	-	-
f)	Roofs	33.5%	40 a	67.3%	0.195	40%
g)	Roof windows, skylights	7.9%	30 a	13.4%	-	46%

Table 1: Costs of deconstruction and expected service lives of envelope components

The calculation of the factor for calculating the dismantling costs $f_{DC,0}$ is calculated from the empirical data of the sample and the cost factor between the replacement of the existing construction and the modernization f_{rep}:

$$f_{DC,0} = \frac{\frac{k_{DC,old,0}}{f_{rep}}}{k_{C,Mod,0}} \tag{7}$$

$f_{DC,0}$: cost factor between demolition and construction of the modernization or the existing building at reference point 0 (i.e., Q3 2024)

$k_{C,Mod,0}$: modernization construction costs (≙ Q3 2024)

$k_{DC,old,0}$: deconstruction costs at the point of modernization (≙ Q3 2024)

f_{rep}: cost factor between modernization and replacement or extensive repairs depending on the component

$$f_{DC,SL} = f_{DC,0} * \frac{(1 + I_{CPI})^{SL}}{(1 + I_{CCI})^{SL}} \tag{8}$$

Since the objective is to compare additional costs of modernizations to the savings, for the best-case scenario, the costs for the deconstructing of the existing structures must be deducted, as this would also be necessary for replacements of the same quality. Therefore, the first deconstruction is allocated to the original life cycle and the second to modernization. The difference in construction and deconstruction costs is calculated using the formulas (9) through (11):

$$\Delta k_{Mod,SL} = k_{Mod,SL} - k_{old,SL} \tag{9}$$

with:

$$k_{old,SL} = k_{C,Mod,0} * f_{rep} * (1 + f_{DC,SL}) \tag{10}$$

$f_{DC,SL}$: cost factor between deconstruction and construction of the old component at the end of their service lives

and:

$$k_{Mod,SL} = k_{C,Mod,0} * (1 + f_{DC,SL}). \tag{11}$$

In the worst-case scenario, dismantling occurs twice in the case of modernization instead of once (without modernization). However, this saves the difference in costs resulting from the early dismantling of the old construction. The fact that these reduced costs arise is due to convention 1a). If these are considered, the following equation applies:

$$\Delta k_{Mod,SL} = k_{Mod,SL} - \left(f_{DC,SL} - f_{DC,0}\right) * f_{rep} * k_{C,Mod,0} \tag{12}$$

$f_{DC,SL}$: factor between deconstruction costs at time 0 and at the end of the components service life

For the best-case scenario, the costs for the new constructions without energy efficiency measures are derived from statistical data. The cost factor between repairing or replacing of components and the modernization measures is calculated based on the most commonly used construction type for each component. The difference is determined for the main (area-related) items and transferred to the cost parameter of the entire cost group as a percentage. For these items and construction types, bills of quantities are compared for the old and new energy efficiency standards, resulting in the factor f_{rep}. This is justified as the length-related work (roof connections, window sills and soffits) must also be carried out at greater expense. This results in the formula:

$$k_{Mod,best-case} = k_{Mod,worst-case} - k_{Rep} \tag{13}$$

k_{Rep}: costs for replacement (or complete overhaul)

The resulting values for f_{rep} are listed in Table 1. The replacement or overhaul costs k_{Rep} are the product of f_{rep} and $k_{C,Mod,0}$. While most of the values for k_{Rep} were calculated assuming replacements of the same thermal quality as the existing constructions, k_{Rep} for windows was calculated with the costs of a complete overhaul, since windows with an equivalent U-value are practically no longer available on the market. It is plausible that as completely overhauled window can achieve a similar service life as a new window.

For the mid-case, the results of the best-case and worst-case are averaged:

$$k_{Mod,mid-case} = \frac{k_{Mod,best-case} + k_{Mod,worst-case}}{2} \tag{14}$$

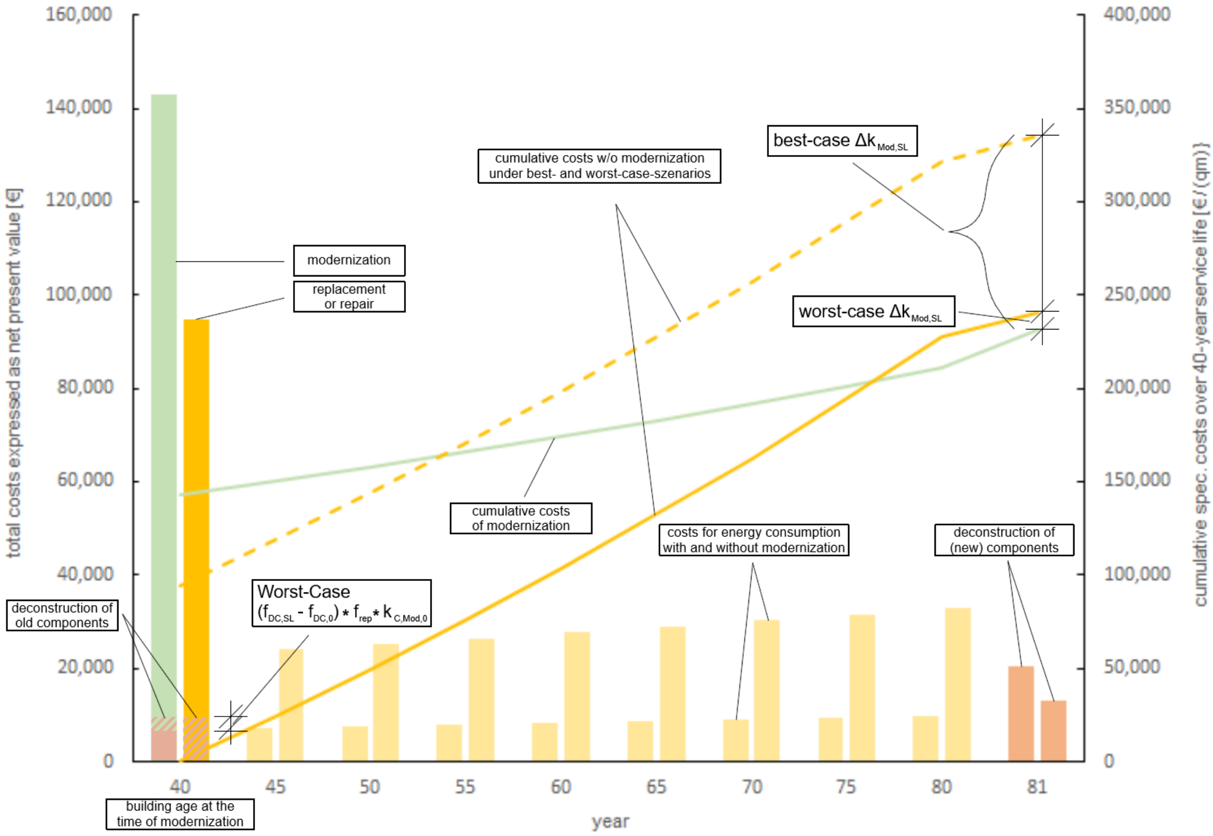


Figure 3: Illustrative example of energy-efficient window modernization (shown on the left in green) versus the same building without modernization (shown on the right in dark yellow)

3. the constructions and surfaces are not changed due to the measures. Therefore, maintenance and costs or smaller repairs remain the same. The service lives and replacement cycles are also unchanged.

The conventions above can be explained using Figure 3. The illustration shows a comparison of variants for a possible window replacement. In this comparison, the break-even point is reached after around 36 years. It should also be noted that the dismantling and disposal costs at the end of life increase due to the new construction and the flat-rate percentage approach. The dismantling costs of the current construction are always attributed to the first life cycle. In the best-case scenario, the break-even point would be reached after around 13 years.

Overall, the following constellations result for the analysis:

Worst-case: The component was in good condition. No repair or replacement would have been necessary in the foreseeable future.

Mid-case: The component was in moderate condition but could have continued to be used with moderate measures.

Best-case: Repair or replacement of the component was necessary anyway.

The econometric regression models are set up based on the modernization costs in construction, without taking the dismantling costs into account.

Expectations

As the buildings and construction elements examined comprise different areas, qualities and design variants, it makes sense to compare the key cost indicators for each construction element. Accordingly, construction elements and quantity approaches are already removed from the explanatory variables. A comparison of area-based cost indicators is common in specialist literature.

The year of construction, the previous and subsequent quality, the location and the influence of quantities on the key cost indicator of the respective construction element can therefore still be considered explanatory variables.

As the construction costs and therefore also the cost indicators have been adjusted by the construction price index, the time of modernization should no longer have a significant influence. If an evaluable correlation nevertheless exists, this would indicate special characteristics of the prices and price trends of energy-related construction measures.

It is generally expected that there is a correlation between the cost indicator and the subsequent energy quality. Due to the degressive effect of increasing thermal insulation on the energy quality (U-value), this should also be degressive with an asymptote at $y = 0$. Since the costs of thicker insulation levels should also be degressive due to non-linearly increasing labor costs and economies of scale in material prices, the possibility of a linear mapping within the investigated limits is plausible. Theoretically, there are also correlations between the cost parameter and the modernized area, which should also show a degressive trend due to economies of scale. However, it is uncertain whether this anticipated low impact can be observed given the small sample size.

Evaluation

General remarks for the evaluation

The following evaluation is based on 57 buildings, where a total of 143 component-specific individual measures were implemented. The list of measures for the different components are supplied at Appendix A to Appendix D. A total of four significant outliers that met the other quality criteria were also excluded. In the following graphs displaying area-related costs and savings over the service life are shown as net present values. Costs are represented by blue dots, and savings by orange dots. Furthermore, the best-, mid- and worst-case scenarios, including their underlying range as indicators, are illustrated using the overall projects.

Windows and exterior doors

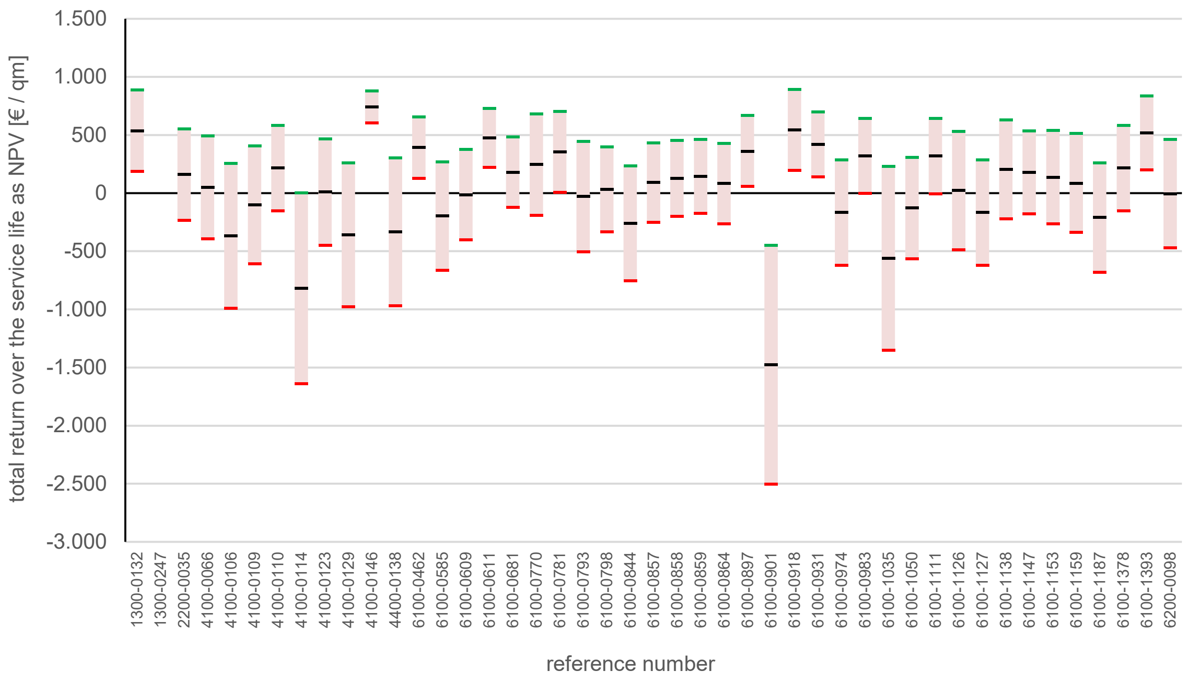


Figure 4: Measure-specific presentation of total return at the end of service life for exterior doors and windows, showing the best-case scenario in green, the mid-case in black, and the worst-case scenario in red

According to Figure 4, 16 out of the 44 evaluated measures (approximately 36%) were not profitable in the mid-case scenario. On average, these measures achieved a return on investment of €46 per square meter of window area, corresponding to about 3.7% over a 40-year service life. In addition to reducing heat transmission losses, modernizing windows also decreased heat losses from infiltration, which are not accounted for. These results are based on average annual savings of 144 kWh of heat energy per square meter. Over a service life of 40 years, the 44 measures implemented across 10,664 square meters yield total savings of over 60,000,000 kWh.

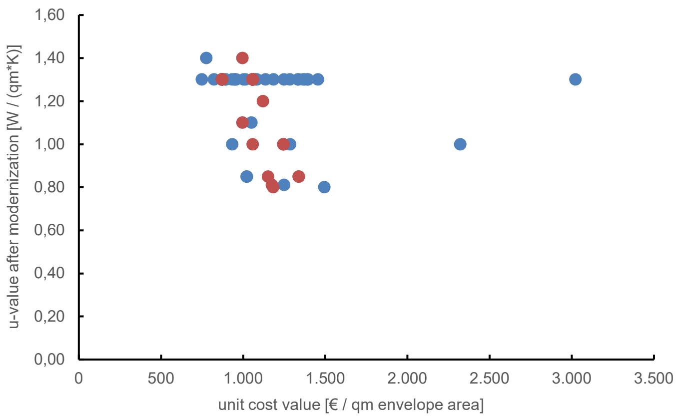


Figure 5: Distribution of cost indicators (blue) and savings (orange) for exterior doors and windows

Figures 4 and 5 show that, over an average service life of 40 years, the measures do not necessarily result in a positive total return when considering the net present value of energy cost savings.

Furthermore, there are no statistically significant correlations between the cost parameter (x-axis) and the possible explanatory variables of year of construction, construction price index (time of start of construction of the modernization) or U-after (standard achieved through modernization).

Overall, the following reasons can be identified for the wide variation in the data:

- Different frame types, which can significantly change the price but have a minor impact on the U-value.
- The available data for calculating window U-values is much less detailed than for elements like external walls; information on the gas fill between panes, edge seals, frame design, or glazing values is often missing.
- The size of the individual windows plays a significant role in the price. Smaller windows are significantly more expensive per square meter. Mullion-transom façades or custom-made products are also more expensive than standard dimensions (e.g. masonry dimensions).
- The quantities (especially for roof windows) are very small, which can lead to additional variation.
- The cost groups are significantly influenced by length-related work (window sills, etc.), which can cause dispersion.

Exterior walls

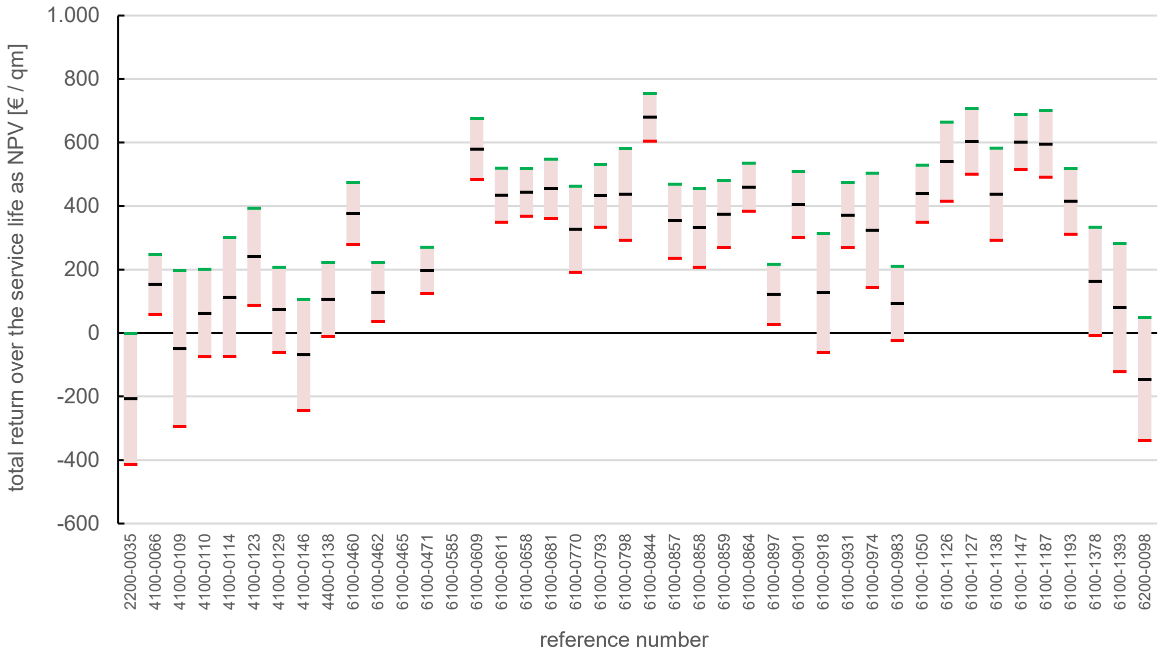


Figure 6: Measure-specific overview of total return after service life for opaque exterior walls (best-case in green, mid-case in black, worst-case in red)

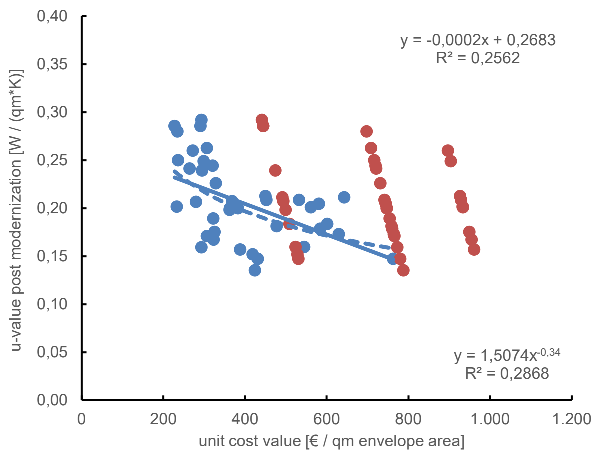
According to Figure 6, a total of four, or 10%, of the 40 measures evaluated were not profitable in the mid-case scenario. On average, these were able to achieve a net present value-related total return of € 290 per square meter of wall area and thus around 73.9% over a service life of 40 years. These results are achieved through saving 90 kWh of heat energy per square meter every year on average. In total over 155,000,00 kWh of heat energy are saved in 42 measures and 43,986 square meters over the components service lives of 40 years.

For the exterior wall surfaces, there are statistically significant ($p \leq 0.05$) correlations with the current cost parameter per square meter for two explanatory variables:

1. $p \leq 0.01$: achieved energy component quality (U-value) after the modernization measure
2. $p \leq 0.05$: construction price index at the start of construction

Incorporating both explanatory variables into a multiple linear regression model results in a reduction of their individual significance. Considering this, along with the similarly high adjusted coefficient of determination (R^2), the development of a multiple regression model is of limited utility.

A simplified linear relationship emerges over the observation horizon. A linear single regression produces the trend line shown in Figure 7. The energy savings per square meter over the lifetime of the measure are shown in orange. The three orange straight lines result from the different initial U-values of the building age classes.



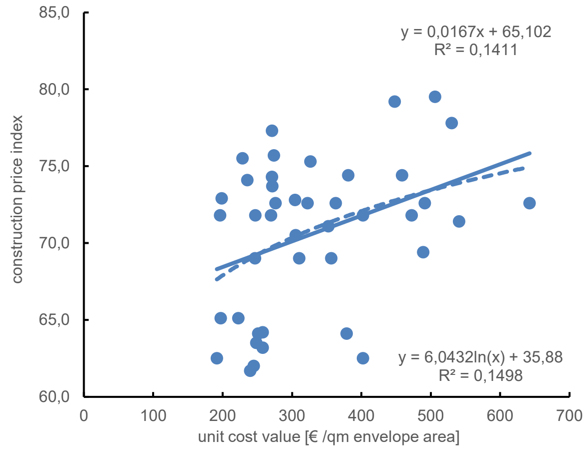


Figure 7: Distribution of cost indicators (blue) and savings (orange) by achieved energy performance and the construction price index for opaque exterior walls

Furthermore, a statistically significant correlation can be identified between the two explanatory variables. The heat transfer coefficient decreases almost linearly with a slope of -0.0042 for every 1.0 increase in the building price index. It can be deduced from this study that the disproportionate price development of the energy modernizations examined can be justified, at least in part, by higher energy standards. In the last decades, German minimum energy standards were raised multiple times, and subsidy requirements became stricter.

Roofs

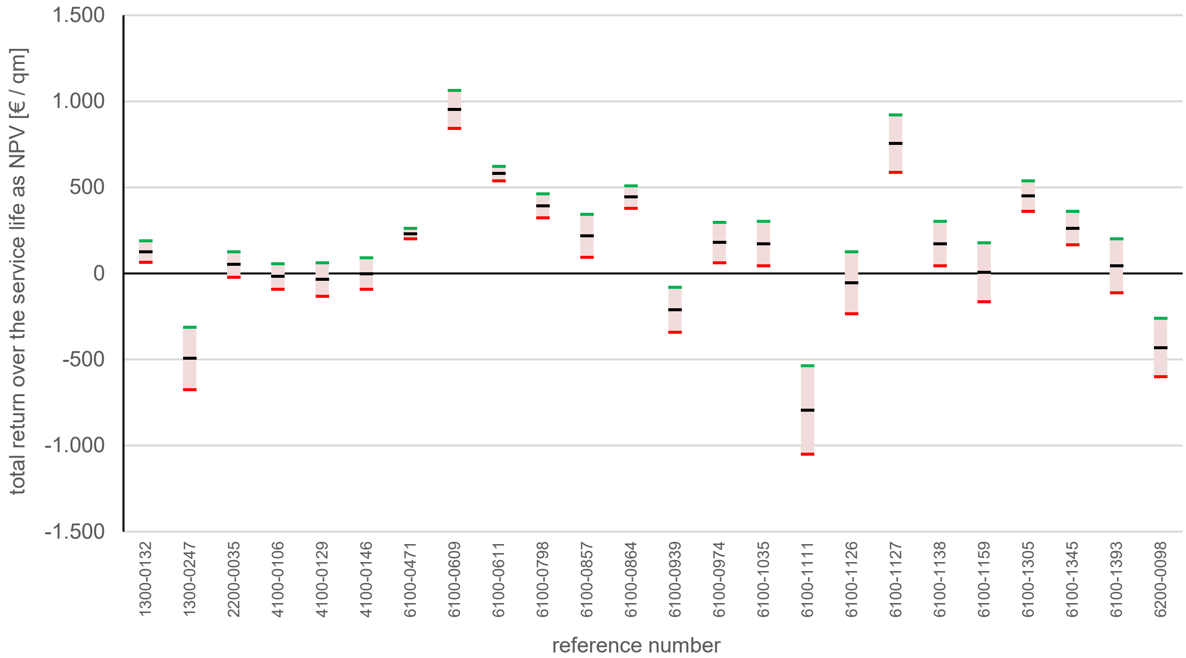


Figure 8: Measure-specific overview of total return after service life for opaque roofs (best-case in green, mid-case in black, worst-case in red)

According to Figure 8, a total of eight, or around 34%, of the 24 measures evaluated were not profitable in the mid-case scenario. On average, these were able to achieve a total return on investment of €125 per square meter of roof area, or around 28.6% over a service life of 40 years. These results are achieved through saving 78 kWh of heat-energy per square meter every year on average. In total over 35,000,000 kWh of heat-energy are saved in 24 measures and 11,580 square meters over the components service life of 40 years.

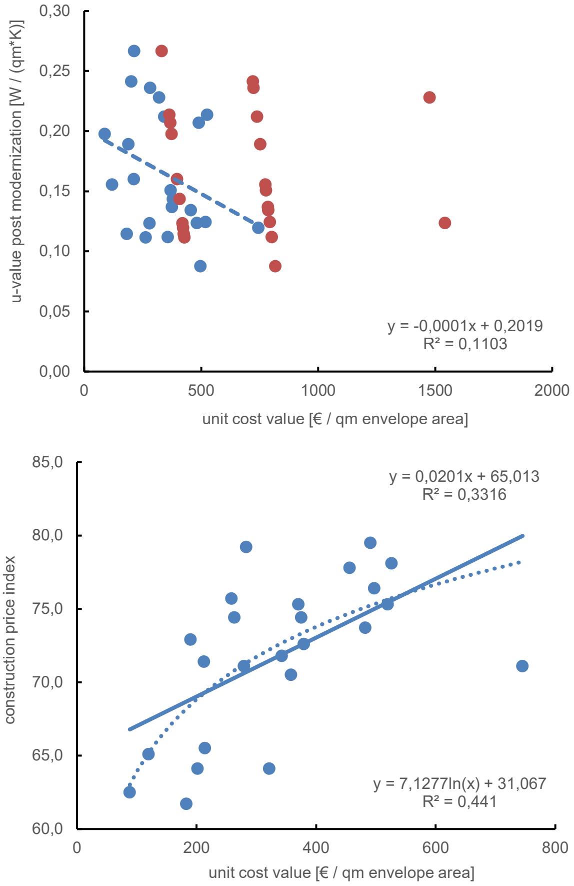


Figure 9: Distribution of cost indicators (blue) and savings (orange) by energy performance and construction price index at the start of construction for opaque roof areas

For the roof areas, there is a statistically significant correlation ($p \leq 0.01$) between the construction cost index at the start of construction and the current cost parameter per square meter. The comparison of costs and savings in Figure 9 does not allow any general statements to be made about the cost-effectiveness of the measures.

Roof windows and skylights

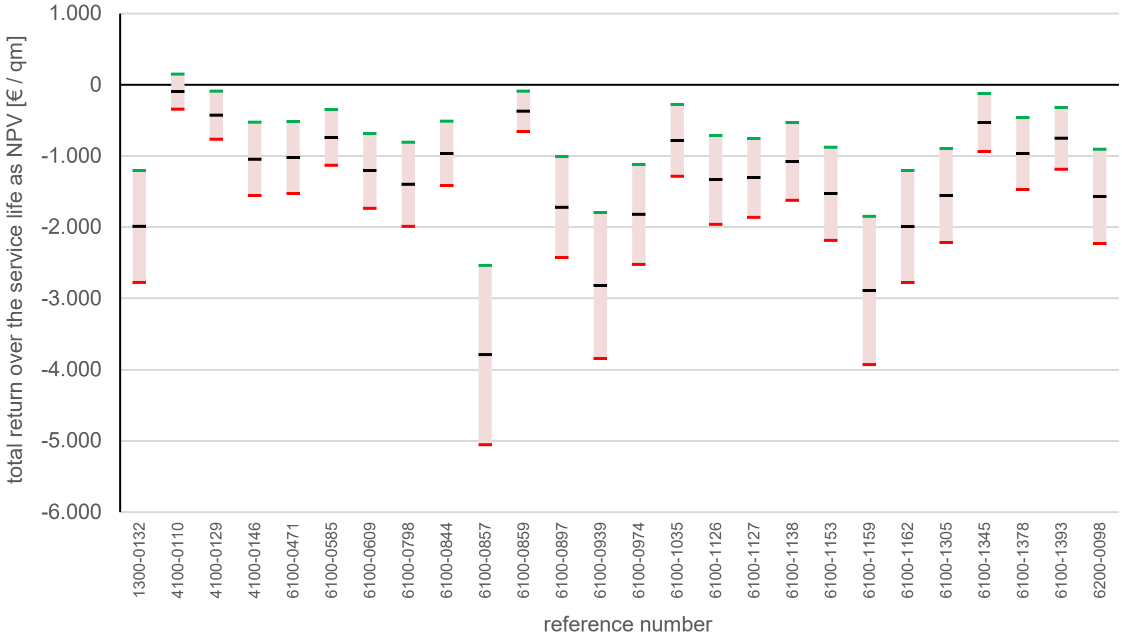


Figure 3: Measure-specific overview of total return after service life for roof windows and skylights (best-case in green, mid-case in black, worst-case in red)

Figure 10 shows that none of the measures examined can generate a capital value-related profit over their lifetime in mid-case scenarios. This is due to the higher price and shorter service life of roof windows compared to windows in exterior walls. On average, these achieved a net present value-related total return of -€1,372 per square meter of window area, or approximately -56.0% over a service life of 30 years. In total over 1,600,000 kWh of heat-energy are saved in 26 measures and 290 square meters over the components service lives of 30 years. Statistically, there are no significant correlations between roof windows and the possible explanatory variables of year of construction, construction price index, or U-after.

Conclusions

Overall, energy-efficiency construction measures in existing buildings can be viewed positively. In total 66.520 square meters of thermal envelope modernizations have been evaluated, saving over 250,000,000 kWh of heat-energy over their service life. Even when inflation is taken into account, through using the net present values, the majority of insulation measures (approximately 60%, including outliers) can generate a positive return. However, these vary significantly depending on the building component. From a macroeconomic perspective, this results in the following order with decreasing overall returns:

1. Exterior walls: mainly composite thermal insulation systems
2. Roof surfaces: mixed as roof cladding and/or roof coverings
3. Windows: mainly double glazing, different frames
4. Skylights: mainly double glazing, different designs

Because all components of the entire building envelope should be insulated for a coherent overall climate and energy strategy, subsidies could be prioritized for those components that tend to yield lower returns. This approach is particularly suitable since the average capital value-related return varies widely from +74% to -56% over the components' lifetimes. The data pool did not reveal any evaluable measures for listed buildings. Additionally, costs for site installation and scaffolding, as well as ancillary construction and financing costs, have not been included; this also applies to possible subsidies.

Due to the reference to the cost groups of DIN 276, usable data is scarce for the top floor ceiling and heated basement rooms (DIN, 2018). Nevertheless, this limitation is acceptable for the following reasons:

- Components for unheated basements and attics generally have lower requirements for surface quality and, as interior components, are subject to significantly lower moisture and temperature stresses than other (exterior) components.
- Ceiling coverings in basements of heated rooms are to be evaluated in approximately the same way as foundation coverings, for which evaluable data can be obtained.

For these two reasons, measures taken on ceilings in unheated basements and attics are generally at the upper end of the economic efficiency scale and thus in terms of expected returns. This also makes sense insofar as both rooms have significantly reduced requirements in terms of usability, surface materials, and visual condition, which means that both production costs are lower and maintenance and repair intervals are longer.

Analyzing measures of existing buildings brings its own challenges, caused by the vast variety of existing constructions. Depending on changes in the façade, (in some cases) hazardous material, construction types and conditions of the constructions, the costs of deconstructing these components varies a lot. By referring to the building envelope after the measures have been carried out as well as proportionally accounting for the demolition costs and using the cost groups of DIN 276 (DIN, 2018), the methodology can be applied to a broad database. With a large enough database, different component varieties – such as flat and sloped roofs – as well as construction types within a component variety (e.g. inverted, cold and warm roof constructions regarding flat roofs) could be examined for modernization and deconstruction costs, further reducing the vast variety of different cost influencing factors and thus also reducing cost influencing factors and therefore the variance in the analyzed data.

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Appendix

Appendix A: List of measures for windows and exterior doors

Nr.	Object-Nr.	Year of construction	Start of modernization	Gross construction price index	Quantities measures check [qm]	Quantities cost group [qm]	Actual costs [€]	Cost indicator [€/qm]	Costs Q2 2024	U-before [W/(qm*K)]	U-after [W/(qm*K)]	Saved energy [kWh/a]	Energy cost savings NPV [€]	Energy cost savings NPV [€/qm]	Return on investment NPV [€]
1	1300-0132	1970	Q4 2003	61.7	187	187	81,676 €	988	184,467 €	3.000	0.850	34,954	250,366	1,339	35.5%
2	1300-0247	1970	Q1 2016	78.1											
3	2200-0035	1972	Q4 2009	71.4	385	385	229,730 €	1,106	425,977 €	3.000	1.300	56,902	407,572	1,059	-4.3%
4	4100-0066	1970	Q4 2001	63.5	351	352	206,299 €	1,245	437,696 €	3.000	1.300	51,877	371,579	1,059	-14.9%
5	4100-0106	1972	Q4 2006	65.5	581	581	476,104 €	1,756	1,020,890 €	3.000	1.300	85,870	615,063	1,059	-39.7%
6	4100-0109	1966	Q1 2009	72.6	696	696	533,379 €	1,428	993,414 €	3.000	1.300	102,866	736,806	1,059	-25.9%
7	4100-0110	1974	Q1 2009	72.6	657	664	370,595 €	1,036	687,688 €	3.000	1.300	97,102	695,519	1,059	2.2%
8	4100-0114	1963	Q4 2007	69.4	334	334	396,486 €	2,315	774,001 €	3.000	1.300	49,364	353,582	1,059	-54.3%
9	4100-0123	1957	Q3 2009	71.8	124	124	93,346 €	1,292	159,777 €	2.700	1.000	18,327	131,270	1,059	-18.1%
10	4100-0129	1972	Q1 2010	71.1	602	610	555,778 €	1,748	1,066,544 €	3.000	1.300	88,973	637,295	1,059	-39.4%
11	4100-0146	1970	Q3 2011	74.4	1,492	1,492	334,961 €	386	576,393 €	3.000	1.300	220,512	1,579,474	1,059	174.0%
12	4400-0138	1970	Q2 2010	72.8	53	52	52,021 €	1,794	93,340 €	3.000	1.200	8,294	59,408	1,121	-37.5%
13	6100-0460	1967	Q4 1999	64.2											
14	6100-0462	1971	Q1 2003	62.0	69	69	22,620 €	745	51,112 €	3.000	1.400	9,598	68,749	996	33.7%
15	6100-0465	1954	Q1 2002	62.5											
16	6100-0471	1972	Q2 2002	62.5											
17	6100-0585	1930	Q4 2003	61.7	40	44	25,224 €	1,318	58,197 €	2.700	1.300	4,869	34,872	872	-33.8%
18	6100-0609	1910	Q2 2006	64.1	24	24	12,696 €	1,090	26,647 €	2.700	1.300	2,921	20,923	872	-20.0%
19	6100-0611	1959	Q3 2006	65.1	39	39	12,759 €	717	27,900 €	3.000	1.300	5,764	41,287	1,059	47.6%
20	6100-0620	1970	Q2 2006	64.1											
21	6100-0658	1958	Q3 2006	65.1											
22	6100-0681	1957	Q2 2007	69.0	76	82	35,653 €	853	69,735 €	2.700	1.300	9,250	66,258	872	2.2%
23	6100-0725	1970	Q3 2008	74.3											
24	6100-0770	1959	Q2 2007	69.0	30	30	18,003 €	1,232	36,967 €	3.000	1.000	5,216	37,363	1,245	1.1%
25	6100-0781	1956	Q4 2004	63.4	152	156	71,565 €	982	153,186 €	2.700	0.850	24,447	175,110	1,152	17.3%
26	6100-0793	1958	Q2 2005	63.2	56	56	34,917 €	1,338	75,561 €	3.000	1.300	8,277	59,283	1,059	-20.9%
27	6100-0798	1929	Q2 2006	64.1	34	37	17,165 €	1,032	38,120 €	2.700	1.300	4,138	29,642	872	-15.5%
28	6100-0844	1926	Q3 2009	71.8	36	36	26,385 €	1,395	50,765 €	2.700	1.300	4,382	31,385	872	-37.5%
29	6100-0857	1954	Q1 2008	70.5	518	517	269,574 €	962	497,540 €	2.700	1.300	63,048	451,599	872	-9.4%
30	6100-0858	1954	Q1 2009	72.6	189	189	93,456 €	919	173,516 €	2.700	1.300	23,004	164,772	872	-5.1%
31	6100-0859	1954	Q1 2009	72.6	161	162	80,467 €	896	144,852 €	2.700	1.300	19,596	140,362	872	-2.6%
32	6100-0864	1954	Q4 2008	72.9	169	168	85,150 €	972	163,154 €	2.700	1.300	20,570	147,336	872	-10.3%
33	6100-0897	1972	Q3 2009	71.8	24	26	12,415 €	858	22,589 €	3.000	1.300	3,547	25,407	1,059	23.4%
34	6100-0901	1956	Q3 2008	74.3	27	27	40,673 €	2,896	77,925 €	2.700	1.300	3,286	23,539	872	-69.9%
35	6100-0918	1960	Q3 2010	72.6	307	307	153,382 €	979	300,119 €	3.000	0.850	57,384	411,028	1,339	36.8%
36	6100-0931	1965	Q3 2009	71.8	273	273	117,364 €	789	215,507 €	3.000	1.300	40,348	289,006	1,059	34.1%
37	6100-0939	1971	Q3 2010	72.6											
38	6100-0974	1932	Q2 2009	71.8	56	56	36,454 €	1,280	71,588 €	2.700	1.300	6,816	48,821	872	-31.9%
39	6100-0983	1972	Q2 2007	69.0	24	24	12,367 €	909	22,135 €	3.000	1.300	3,547	25,407	1,059	16.5%
40	6100-1035	1963	Q1 2012	75.3	9	9	12,020 €	2,226	19,501 €	3.000	1.000	1,565	11,209	1,245	-44.1%
41	6100-1050	1956	Q2 2011	74.1	1,091	1,091	730,398 €	1,231	1,343,270 €	2.700	1.300	132,791	951,147	872	-29.2%
42	6100-1111	1971	Q1 2010	71.1	615	615	283,184 €	911	560,266 €	3.000	1.300	90,895	651,057	1,059	16.2%
43	6100-1126	1938	Q1 2012	75.3	24	24	18,394 €	1,432	34,233 €	2.700	0.800	3,964	28,396	1,183	-17.4%
44	6100-1127	1886	Q1 2011	73.7	36	36	25,131 €	1,280	46,555 €	2.700	1.300	4,382	31,385	872	-31.9%
45	6100-1138	1944	Q3 2011	74.4	38	38	25,391 €	1,198	45,400 €	2.700	0.811	6,242	44,712	1,177	-1.8%
46	6100-1147	1936	Q2 2012	75.5	48	48	26,139 €	1,008	48,406 €	2.700	1.100	6,677	47,825	996	-1.1%
47	6100-1153	1959	Q3 2013	76.7	41	46	28,233 €	1,136	51,913 €	3.000	1.300	6,060	43,404	1,059	-6.8%
48	6100-1159	1967	Q2 2013	76.4	27	27	18,248 €	1,198	32,685 €	3.000	1.300	3,991	28,583	1,059	-11.6%
49	6100-1162	1976	Q3 2012	75.7											
50	6100-1187	1910	Q3 2012	75.7	42	41	30,545 €	1,332	55,209 €	2.700	1.300	5,112	36,616	872	-34.5%
51	6100-1192	1966	Q2 2014	77.3											
52	6100-1193	1966	Q2 2014	77.3											
53	6100-1305	1962	Q3 2012	75.7											
54	6100-1345	1962	Q2 2016	79.2											
55	6100-1378	1964	Q2 2016	79.2	45	54	33,529 €	1,040	56,086 €	3.000	1.300	6,651	47,638	1,059	1.8%
56	6100-1393	1960	Q1 2015	77.8	23	24	11,658 €	896	21,331 €	3.000	1.000	3,999	28,645	1,245	39.0%
57	6200-0098	1975	Q3 2016	79.5	859	859	678,411 €	1,310	1,125,720 €	3.000	1.300	126,957	909,362	1,059	-19.2%

Index Q3 2024	123.7

Complete list	**10,664**	**10,712**	**6,429,945 €**	**1,133**	**12,137,877 €**			**1,534,335**	**10,990,062**	**1,031**

Appendix B: List of measures for exterior walls

Nr.	Object-Nr.	Year of construction	Start of modernization	Gross construction price index	Quantities measures check [qm]	Quantities cost group [qm]	Actual costs [€]	Cost indicator [€/qm]	Costs Q2 2024	U-before [W/(qm*K)]	U-after [W/(qm*K)]	Saved energy [kWh/a]	Energy cost savings NPV [€]	Energy cost savings NPV [€/qm]	Return on Investment NPV [€]
1	1300-0132	1970	Q4 2003	61.7											
2	1300-0247	1970	Q1 2016	78.1											
3	2200-0035	1972	Q4 2009	71.4	1,090	1,123	350,426 €	541	607,111 €	1.000	0.211	74,751	535,420	491	-9.2%
4	4100-0066	1970	Q4 2001	63.5	3,829	3,900	497,196 €	248	968,553 €	1.000	0.239	253,302	1,814,343	474	90.8%
5	4100-0106	1972	Q4 2006	65.5											
6	4100-0109	1966	Q1 2009	72.6	775	854	321,844 €	642	548,376 €	1.400	0.147	84,407	604,584	780	21.4%
7	4100-0110	1974	Q1 2009	72.6	2,577	2,577	548,779 €	363	935,040 €	1.000	0.147	191,045	1,368,409	531	46.3%
8	4100-0114	1963	Q4 2007	69.4	1,384	1,493	409,569 €	489	730,024 €	1.400	0.205	143,842	1,030,302	744	52.3%
9	4100-0123	1957	Q3 2009	71.8	986	986	230,234 €	402	396,656 €	1.400	0.181	104,485	748,397	759	88.7%
10	4100-0129	1972	Q1 2010	71.1	1,307	1,439	291,501 €	352	507,154 €	1.000	0.152	96,371	690,280	528	49.9%
11	4100-0146	1970	Q3 2011	74.4	2,382	2,382	656,714 €	458	1,091,876 €	1.000	0.160	174,030	1,246,533	523	14.2%
12	4400-0138	1970	Q2 2010	72.8	1,122	1,082	193,871 €	305	329,420 €	1.000	0.198	78,196	560,100	499	63.9%
13	6100-0460	1967	Q4 1999	64.2	426	426	56,946 €	258	109,723 €	1.400	0.262	42,131	301,774	708	174.9%
14	6100-0462	1971	Q1 2003	62.0	700	700	85,870 €	245	171,324 €	1.000	0.286	43,470	311,361	445	81.8%
15	6100-0465	1954	Q1 2002	62.5											
16	6100-0471	1972	Q2 2002	62.5	182	182	17,628 €	192	34,889 €	1.000	0.286	11,302	80,954	445	132.0%
17	6100-0585	1930	Q4 2003	61.7											
18	6100-0609	1910	Q2 2006	64.1	85	96	12,490 €	251	24,104 €	1.700	0.249	10,723	76,806	904	259.5%
19	6100-0611	1959	Q3 2006	65.1	258	258	30,234 €	223	57,450 €	1.400	0.241	25,988	186,147	721	224.0%
20	6100-0620	1970	Q2 2006	64.1											
21	6100-0658	1958	Q3 2006	65.1	2,801	2,801	290,964 €	197	552,876 €	1.400	0.280	272,738	1,953,556	697	253.3%
22	6100-0681	1957	Q2 2007	69.0	515	515	70,785 €	247	126,901 €	1.400	0.159	55,551	397,901	773	213.3%
23	6100-0725	1970	Q3 2008	74.3											
24	6100-0770	1959	Q2 2007	69.0	318	318	63,271 €	357	113,429 €	1.400	0.135	34,971	250,488	788	120.8%
25	6100-0781	1956	Q4 2004	63.4											
26	6100-0793	1958	Q2 2005	63.2	235	235	30,947 €	258	60,571 €	1.400	0.171	25,115	179,891	765	197.0%
27	6100-0798	1929	Q2 2006	64.1	131	131	25,704 €	379	49,604 €	1.700	0.212	16,942	121,354	926	144.5%
28	6100-0844	1926	Q3 2009	71.8	264	264	30,096 €	196	51,851 €	1.700	0.201	34,394	246,355	933	375.4%
29	6100-0857	1954	Q1 2008	70.5	3,540	3,492	607,568 €	305	1,066,045 €	1.400	0.200	369,317	2,645,327	747	144.7%
30	6100-0858	1954	Q1 2009	72.6	1,357	1,352	255,655 €	322	435,600 €	1.400	0.200	141,572	1,014,042	747	131.9%
31	6100-0859	1954	Q1 2009	72.6	1,369	1,451	235,360 €	276	401,019 €	1.400	0.226	139,752	1,001,009	731	164.5%
32	6100-0864	1954	Q4 2008	72.9	710	704	82,273 €	198	139,605 €	1.400	0.250	70,984	508,439	716	260.9%
33	6100-0897	1972	Q3 2009	71.8	244	244	34,915 €	247	60,153 €	1.000	0.292	15,022	107,597	441	78.5%
34	6100-0901	1956	Q3 2008	74.3	165	165	26,914 €	271	44,809 €	1.400	0.189	17,369	124,410	754	178.3%
35	6100-0918	1960	Q3 2010	72.6	843	848	244,530 €	492	416,645 €	1.400	0.178	89,524	641,240	761	54.7%
36	6100-0931	1965	Q3 2009	71.8	1,122	1,246	195,069 €	270	336,074 €	1.400	0.244	112,768	807,729	720	167.0%
37	6100-0939	1971	Q3 2010	72.6											
38	6100-0974	1932	Q2 2009	71.8	207	222	60,756 €	472 €	104,673 €	1.700	0.201	26,978	193,240	934	97.6%
39	6100-0983	1972	Q2 2007	69.0	192	204	35,386 €	310	63,438 €	1.000	0.207	13,231	94,772	494	59.0%
40	6100-1035	1963	Q1 2012	75.3											
41	6100-1050	1956	Q2 2011	74.1	3,025	3,333	470,636 €	236	785,663 €	1.400	0.207	313,872	2,248,186	743	215.3%
42	6100-1111	1971	Q1 2010	71.1											
43	6100-1126	1938	Q1 2012	75.3	122	135	26,824 €	326	44,065 €	1.700	0.157	16,366	117,224	961	194.4%
44	6100-1127	1886	Q1 2011	73.7	269	269	43,559 €	272	73,110 €	1.700	0.167	35,846	256,757	954	251.3%
45	6100-1138	1944	Q3 2011	74.4	180	183	41,920 €	381	69,698 €	1.700	0.208	23,341	167,184	929	143.9%
46	6100-1147	1936	Q2 2012	75.5	220	220	30,663 €	229	50,239 €	1.700	0.260	27,542	197,279	897	292.2%
47	6100-1153	1959	Q3 2013	76.7											
48	6100-1159	1967	Q2 2013	76.4											
49	6100-1162	1976	Q3 2012	75.7											
50	6100-1187	1910	Q3 2012	75.7	248	256	42,950 €	274	70,184 €	1.700	0.175	32,873	235,462	949	246.4%
51	6100-1192	1966	Q2 2014	77.3											
52	6100-1193	1966	Q2 2014	77.3	989	1,052	178,254 €	271	285,252 €	1.400	0.172	105,604	756,414	765	181.9%
53	6100-1305	1962	Q3 2012	75.7											
54	6100-1345	1962	Q2 2016	79.2											
55	6100-1378	1964	Q2 2016	79.2	270	274	78,692 €	448	122,906 €	1.400	0.209	27,966	200,312	742	65.5%
56	6100-1393	1960	Q1 2015	77.8	211	210	70,082 €	530	111,428 €	1.400	0.173	22,508	161,221	764	44.1%
57	6200-0098	1975	Q3 2016	79.5	6,613	6,613	2,151,427 €	506	3,347,566 €	1.000	0.184	469,329	3,361,687	508	0.4%

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Complete list	**43,263**	**44,232**	**9,128,503 €**	**350**	**15,495,106 €**	**0 €**	**0 €**	**3,845,517**	**27,544,485**	**623**

Appendix C: List of measures for roofs

Nr.	Object-Nr.	Year of construction	Start of modernization	Gross construction price index	Quantities measures check [qm]	Quantities cost group [qm]	Actual costs [€]	Cost indicator [€/qm]	Costs Q2 2024	U-before [W/(qm*K)]	U-after [W/(qm*K)]	Saved energy [kWh/a]	Energy cost savings NPV [€]	Energy cost savings NPV [€/qm]	Return on Investment NPV [€]
1	1300-0132	1970	Q4 2003	61.7	767	767	70,216 €	184	140,773 €	0.800	0.115	45,707	327,385	427	132.6%
2	1300-0247	1970	Q1 2016	78.1	200	200	66,601 €	526	105,487 €	0.800	0.214	10,194	73,015	365	-30.6%
3	2200-0035	1972	Q4 2009	71.4	904	912	111,935 €	213	193,926 €	0.800	0.160	50,299	360,283	399	87.5%
4	4100-0066	1970	Q4 2001	63.5											
5	4100-0106	1972	Q4 2006	65.5	481	481	54,506 €	214	102,938 €	0.800	0.267	22,303	159,749	332	55.1%
6	4100-0109	1966	Q1 2009	72.6											
7	4100-0110	1974	Q1 2009	72.6											
8	4100-0114	1963	Q4 2007	69.4											
9	4100-0123	1957	Q3 2009	71.8											
10	4100-0129	1972	Q1 2010	71.1	1,282	1,282	206,097 €	280	358,569 €	0.800	0.123	75,417	540,192	421	50.7%
11	4100-0146	1970	Q3 2011	74.4	2,731	2,731	433,220 €	264	720,286 €	0.800	0.112	163,458	1,170,810	429	62.6%
12	4400-0138	1970	Q2 2010	72.8											
13	6100-0460	1967	Q4 1999	64.2											
14	6100-0462	1971	Q1 2003	62.0											
15	6100-0465	1954	Q1 2002	62.5											
16	6100-0471	1972	Q2 2002	62.5	81	81	3,627 €	88	7,179 €	0.800	0.198	4,252	30,458	375	324.2%
17	6100-0585	1930	Q4 2003	61.7											
18	6100-0609	1910	Q2 2006	64.1	170	170	28,353 €	322	54,715 €	2.600	0.228	35,056	251,099	1,477	358.9%
19	6100-0611	1959	Q3 2006	65.1	102	102	6,437 €	120	12,231 €	1.400	0.156	11,035	79,044	775	546.3%
20	6100-0620	1970	Q2 2006	64.1											
21	6100-0658	1958	Q3 2006	65.1											
22	6100-0681	1957	Q2 2007	69.0											
23	6100-0725	1970	Q3 2008	74.3											
24	6100-0770	1959	Q2 2007	69.0											
25	6100-0781	1956	Q4 2004	63.4											
26	6100-0793	1958	Q2 2005	63.2											
27	6100-0798	1929	Q2 2006	64.1	77	77	8,061 €	202	15,555 €	1.400	0.241	7,756	55,555	721	257.1%
28	6100-0844	1926	Q3 2009	71.8											
29	6100-0857	1954	Q1 2008	70.5	2,156	2,157	440,249 €	358	772,465 €	1.400	0.112	241,462	1,729,531	802	124.0%
30	6100-0858	1954	Q1 2009	72.6											
31	6100-0859	1954	Q1 2009	72.6											
32	6100-0864	1954	Q4 2008	72.9	28	28	3,126 €	190	5,305 €	1.400	0.189	2,947	21,112	754	296.5%
33	6100-0897	1972	Q3 2009	71.8											
34	6100-0901	1956	Q3 2008	74.3											
35	6100-0918	1960	Q3 2010	72.6											
36	6100-0931	1965	Q3 2009	71.8											
37	6100-0939	1971	Q3 2010	72.6	89	89	19,756 €	380	33,661 €	0.800	0.144	5,079	36,380	409	7.7%
38	6100-0974	1932	Q2 2009	71.8	137	146	29,138 €	343	50,200 €	1.400	0.212	14,148	101,342	740	115.6%
39	6100-0983	1972	Q2 2007	69.0											
40	6100-1035	1963	Q1 2012	75.3	92	92	20,770 €	371	34,120 €	1.400	0.151	9,993	71,579	778	109.8%
41	6100-1050	1956	Q2 2011	74.1											
42	6100-1111	1971	Q1 2010	71.1	762	762	326,244 €	745	567,600 €	0.800	0.120	45,079	322,889	424	-43.1%
43	6100-1126	1938	Q1 2012	75.3	131	131	41,512 €	520	68,195 €	1.400	0.124	14,527	104,055	794	52.7%
44	6100-1127	1886	Q1 2011	73.7	97	96	27,727 €	483	46,538 €	2.600	0.123	20,885	149,593	1,542	219.4%
45	6100-1138	1944	Q3 2011	74.4	264	262	59,127 €	376	98,306 €	1.400	0.137	28,989	207,643	787	109.4%
46	6100-1147	1936	Q2 2012	75.5											
47	6100-1153	1959	Q3 2013	76.7											
48	6100-1159	1967	Q2 2013	76.4	228	228	70,189 €	497	113,644 €	1.400	0.088	26,017	186,350	817	64.3%
49	6100-1162	1976	Q3 2012	75.7											
50	6100-1187	1910	Q3 2012	75.7											
51	6100-1192	1966	Q2 2014	77.3											
52	6100-1193	1966	Q2 2014	77.3											
53	6100-1305	1962	Q3 2012	75.7	200	209	33,070 €	259	54,039 €	1.400	0.000	24,343	174,362	872	236.8%
54	6100-1345	1962	Q2 2016	79.2	130	145	26,232 €	283	40,971 €	1.400	0.236	13,157	94,238	725	155.9%
55	6100-1378	1964	Q2 2016	79.2											
56	6100-1393	1960	Q1 2015	77.8	132	132	37,892 €	456	60,247 €	1.400	0.134	14,528	104,057	788	72.7%
57	6200-0098	1975	Q3 2016	79.5	339	339	107,035 €	491	166,544 €	0.800	0.207	17,482	125,218	369	-24.7%

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Complete list	**11,580**	**11,620**	**2,231,118 €**	**329**	**3,823,493 €**	**0 €**	**0 €**	**904,113**	**6,475,940**	**557**

Appendix D: List of measures for roofs

Nr.	Object-Nr.	Year of construction	Start of modernization	Gross construction price index	Quantities measures check [qm]	Quantities cost group [qm]	Actual costs [€]	Cost indicator [€/qm]	Costs Q2 2024	U-before [W/(qm*K)]	U-after [W/(qm*K)]	Saved energy [kWh/a]	Energy cost savings NPV [€]	Energy cost savings NPV [€/qm]	Return on Investment NPV [€]
1	1300-0132	1970	Q4 2003	61.7	4	4	6,958 €	3,185	13,950 €	3.000	1.300	591	3,033	758	-76.2%
2	1300-0247	1970	Q1 2016	78.1											
3	2200-0035	1972	Q4 2009	71.4											
4	4100-0066	1970	Q4 2001	63.5											
5	4100-0106	1972	Q4 2006	65.5											
6	4100-0109	1966	Q1 2009	72.6											
7	4100-0110	1974	Q1 2009	72.6	172	175	113,787 €	991	193,876 €	3.000	1.300	25,421	130,413	758	-23.5%
8	4100-0114	1963	Q4 2007	69.4											
9	4100-0123	1957	Q3 2009	71.8											
10	4100-0129	1972	Q1 2010	71.1	18	18	14,437 €	1,372	25,118 €	3.000	1.300	2,660	13,648	758	-44.7%
11	4100-0146	1970	Q3 2011	74.4	1	1	854 €	2,086	1,420 €	3.000	1.300	95	485	758	-63.7%
12	4400-0138	1970	Q2 2010	72.8											
13	6100-0460	1967	Q4 1999	64.2											
14	6100-0462	1971	Q1 2003	62.0											
15	6100-0465	1954	Q1 2002	62.5											
16	6100-0471	1972	Q2 2002	62.5	2	2	2,649 €	2,066	5,243 €	3.000	1.300	296	1,516	758	-63.3%
17	6100-0585	1930	Q4 2003	61.7	1	1	973 €	1,585	1,950 €	2.700	1.300	146	749	624	-60.6%
18	6100-0609	1910	Q2 2006	64.1	10	10	10,709 €	2,126	20,666 €	2.700	1.300	1,095	5,620	578	-72.8%
19	6100-0611	1959	Q3 2006	65.1											
20	6100-0620	1970	Q2 2006	64.1											
21	6100-0658	1958	Q3 2006	65.1											
22	6100-0681	1957	Q2 2007	69.0											
23	6100-0725	1970	Q3 2008	74.3											
24	6100-0770	1959	Q2 2007	69.0											
25	6100-0781	1956	Q4 2004	63.4											
26	6100-0793	1958	Q2 2005	63.2											
27	6100-0798	1929	Q2 2006	64.1	2	2	2,282 €	2,393	4,403 €	2.700	1.200	261	1,338	669	-72.0%
28	6100-0844	1926	Q3 2009	71.8	3	3	3,640 €	1,844	6,271 €	2.700	1.300	365	1,873	624	-66.1%
29	6100-0857	1954	Q1 2008	70.5	3	3	9,818 €	5,142	17,226 €	2.700	1.300	365	1,873	624	-87.9%
30	6100-0858	1954	Q1 2009	72.6											
31	6100-0859	1954	Q1 2009	72.6	10	10	6,747 €	1170	11,496 €	2.700	1.300	1,217	6,244	624	-46.6%
32	6100-0864	1954	Q4 2008	72.9											
33	6100-0897	1972	Q3 2009	71.8	2	2	3,596 €	3,098	6,195 €	3.000	1.300	296	1,516	758	-75.5%
34	6100-0901	1956	Q3 2008	74.3											
35	6100-0918	1960	Q3 2010	72.6											
36	6100-0931	1965	Q3 2009	71.8											
37	6100-0939	1971	Q3 2010	72.6	0	0	889 €	4,208	1,515 €	3.000	1.300	53	273	758	-82.0%
38	6100-0974	1932	Q2 2009	71.8	2	2	3,084 €	2,872	5,314 €	2.700	1.300	243	1,249	624	-78.3%
39	6100-0983	1972	Q2 2007	69.0											
40	6100-1035	1963	Q1 2012	75.3	2	2	1,971 €	2,024	3,238 €	3.000	0.840	376	1,927	963	-52.4%
41	6100-1050	1956	Q2 2011	74.1											
42	6100-1111	1971	Q1 2010	71.1											
43	6100-1126	1938	Q1 2012	75.3	3	3	4,870 €	2,573	8,001 €	2.700	0.840	485	2,489	830	-67.8%
44	6100-1127	1886	Q1 2011	73.7	4	3	4,307 €	2,266	7,229 €	2.700	1.300	487	2,498	624	-72.4%
45	6100-1138	1944	Q3 2011	74.4	3	3	3,702 €	2,246	6,154 €	2.700	0.840	485	2,489	830	-63.1%
46	6100-1147	1936	Q2 2012	75.5											
47	6100-1153	1959	Q3 2013	76.7	1	1	1,513 €	2,652	2,440 €	3.000	1.300	148	758	758	-71.4%
48	6100-1159	1967	Q2 2013	76.4	10	10	27,251 €	4,230	44,123 €	3.000	1.300	1,542	7,908	758	-82.1%
49	6100-1162	1976	Q3 2012	75.7	7	7	12,794 €	3,211	20,907 €	3.000	1.300	1,035	5,308	758	-76.4%
50	6100-1187	1910	Q3 2012	75.7											
51	6100-1192	1966	Q2 2014	77.3											
52	6100-1193	1966	Q2 2014	77.3											
53	6100-1305	1962	Q3 2012	75.7	7	7	12,794 €	3,211	20,907 €	3.000	1.300	1,035	5,308	758	-76.4%
54	6100-1345	1962	Q2 2016	79.2	5	5	5,565 €	1,704	8,692 €	3.000	1.000	869	4,460	892	-47.7%
55	6100-1378	1964	Q2 2016	79.2	4	3	4,801 €	2,174	7,499 €	3.000	1.200	626	3,211	803	-63.1%
56	6100-1393	1960	Q1 2015	77.8	7	7	7,512 €	1,785	11,943 €	3.000	1.300	1,035	5,308	758	-57.5%
57	6200-0098	1975	Q3 2016	79.5	7	7	13,572 €	2,897	21,118 €	3.000	1.300	1,035	5,308	758	-73.8%

Index Q3 2024	123.7

Complete list	**290**	**291**	**281,076 €**	**1,637**	**476,895 €**	**0 €**	**0 €**	**42,260**

Über die Autoren

Alexander Henkel ist Gastwissenschaftler an der Technischen Hochschule Mittelhessen und hauptberuflich Koordinator für energieeffizientes und nachhaltiges Bauen für das Land Hessen. Sowohl im Studium und seinen Abschlussarbeiten sowie in seiner Forschung legte er den Fokus auf nachhaltiges Bauen in wirtschaftlicher und ökologischer Hinsicht.

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