International Journal of Economics and Financial Issues

ISSN: 2146-4138

available at http: www.econjournals.com

International Journal of Economics and Financial Issues, 2025, 15(4), 63-71.

Economic Viability of Efficiency Houses for Social Housing in Germany

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Received: 06 September 2024 **Accepted:** 25 April 2025 **DOI:** https://doi.org/10.32479/ijefi.16998

ABSTRACT

In Germany, the construction of new residential buildings for social housing has significantly declined, while the demand for such housing has steadily increased. This study aimed to identify the economic conditions necessary to enable affordable rents for social housing in Germany, considering various financial and policy parameters. A mixed-methods approach was employed, utilizing both qualitative and quantitative data from 45 realized mid-range residential buildings meeting EH 40 and EH 55 energy standards. The methodology included detailed profitability calculations performed using the dynamic net present value method, incorporating variables such as investment costs, rent adjustments, discount rates, financing periods, and tax rates. Sensitivity analyses and Monte Carlo simulations were conducted to assess the impact of these variables on investment requirements and initial rent levels. The results indicate that rent adjustments have the greatest impact on required investments, followed by discount rates and financing periods. Specifically, a 0.5% increase in rent adjustment necessitates higher initial investment costs of approximately €124/m^2/month. The simulations also highlighted the significant influence of discount rates on initial rents, with nearly one euro per square meter increase for a 1% rise in interest rates. The findings suggest that while current policies and subsidies help reduce investment costs, additional measures such as social funds are needed to ensure financial viability and affordability. In conclusion, the study highlights the need for comprehensive economic strategies to support the development of energy-efficient social housing in Germany. The implications of these findings are crucial for policymakers and investors aiming to balance economic viability with social sustainability.

Keywords: Energy-Efficient Housing, Economic Viability, Social Housing, Sustainability
JEL Classifications: R310, R380

1. INTRODUCTION

Housing is becoming increasingly scarce and not just in Germany (Ryan-Collins, 2021; Shahab et al., 2021; Ulbrich and Wullkopf, 2021). Increased demand due to the construction boom combined with low interest rates, immigration (war of aggression in Ukraine, asylum policy), the unlawful use of social housing, and the deficit in building for people on lower incomes has exacerbated the situation (Galvin, 2023; Kindermann et al., 2021; Rink and Egner, 2022). Together with demand, the energy requirements of new buildings must be low so that Germany's climate protection targets can be achieved (Galvin, 2024; Hancock et al., 2023). But what - in addition to political and social measures - are the economic framework conditions for social housing to be realized? Various papers and reports address part of this question (Hasper et al., 2021; Marquardt and Glaser, 2023). The involvement of both business partners, the investor or the building cooperative, and the tenants has not yet been considered. This paper considered what financial conditions the investor needs to create the building and what rents the future occupant will have to pay for this energy-efficient building. Only if both are satisfied will the project be realized. The study is based on 45 realized mid-range residential buildings whose energy standard corresponds to an efficiency house EH 40 and EH 55. The investment costs including risks, ancillary costs, profits, etc. are already included in the investment costs. These costs were passed on to KfW Bank for the funding applications. The energy data is also available based on the energy certificates for the efficiency houses that we prepared ourselves. Based on the investment costs and the categorization of the efficiency buildings, profitability calculations can be carried out using the dynamic net present value method. These offer the advantage of incorporating future monetary developments and thus providing a reliable basis for decisions on investments and rental payments.

This study examined the financial framework conditions that enable investors to rent out their apartments as energy-saving efficiency houses at a socially acceptable rent. Rent increases, discount rates, the financing period, and taxes are considered based on the reduced investment costs and the reduced rents. Subsidies from the state or local authorities and, where applicable, from the KfW Bank are deducted from the investment costs of the energy-efficient apartment buildings examined. A lower-cost construction method is assumed.

2. LITERATURE REVIEW

Few studies have examined the economic efficiency of efficiency houses in social housing in Germany in the context of investors (landlords) and tenants. Some studies deal with parts of the topic. One relevant study is by Taruttis and Weber (2022) which categorized various apartment buildings from a BKI study. This allows the rents to be linked to the investment costs. Further investigations are based on occupied social buildings whereby the energy consumption was measured (Bohnenberger, 2021). In Belotti and Arbaci (2021), the risks for the development of social housing in Italy are considered. It is assumed here that profitability is possible. It even assumes high-profit margins for the developer of 11-43%. In a study with the most objects of investigation, 760 thousand were carried out in 403 local markets in Germany (Galvin, 2024). As a result, it was found that energy-efficient homes are rented at a maximum price. However, this was not true for the major cities. It was also found that energy-efficient buildings are easier to rent out than less efficient buildings. The buildings are renovated and unrenovated and therefore not directly comparable with new buildings. A large number of parameters are shown but no direct correlation between tenant and landlord (investor). A study of energy-efficient refurbished residential buildings in Germany compares measured energy consumption after energy refurbishment with the calculated energy requirements (Çetin et al., 2021). The annual rent is between €6 and €13.20/(m^2/month) and the rent increases are between 0.77% and 2.79%/(m^2a). However, this is not social housing. Chegut et al. (2020) included the risks in their consideration of the capital value and formed a "risk-adjusted NPV". He also presents a stochastic NPV which considers each component of the cash flow that has a probability distribution. However, his study refers to innovation projects whose realization involves financial risks (Chegut et al., 2020). It provides a broad overview of social housing in Europe, qualitatively highlighting various aspects such as financing, funding, and access to social housing. The average rents in social housing are stated to be between €4 and €7/(m^2/month) (p16). However, the figures refer to the year 2007, so today (2024) with an average rent increase of 1.5 %/a, rents of between €5.15 and €9.03/(m^2/month) must be expected. A comprehensive study also concludes that although there is literature on investors, little or no attention is paid to tenants (Debrunner and Hartmann, 2020). It is argued here that landlords could not fully transfer costs to tenants. The paper provides an equation for the net present value which is subject to the risk factor of the apartment occupancy to obtain the maximum net present value (the market value 2020 p. 9). A hedonic equation is set up that takes into account the energy performance score EPS. However, buildings with and without EPS are rented at almost the same rents €7.35/(m^2/month) with EPS and €7.32/(m^2/month) without EPS (p.18). An article by the European Union assumes higher rents if the buildings have a better energy efficiency standard. Here 3-5% higher rents are stated (Fuerst et al., 2020). Considerations for reducing ancillary costs in social housing are mentioned in "Approaches to reducing ancillary costs in social housing using the example of the 'PassivHausSozialPlus' project in Darmstadt" (2018). At €0.14/(m^2/month), the heating costs for new buildings are only around half of the costs for hot water (€0.32/[m^2/month]). With regard to the motivation to do something for the financially disadvantaged, there are opportunities to pay into a social fund but there are no parameters or even a standardized seal that would document how socially responsible and sustainable the investor is through their socially responsible investment (SRI) (Medved et al., 2020). The survey in the USA shows that the majority of respondents (without and with SRI) are in favor of environmental concerns (72-84%) (p. 715). Although the survey relates to US investors, it can be assumed that the same motivation exists in Europe or rather Germany as evidenced by the large number of seals that refer to energy saving and sustainability (KfW Efficiency Houses, Climate Friendly Bonus, Quality Seal for Sustainable Buildings (QNG), LEED, CESBA).

Several other studies have highlighted the economic and social implications of energy-efficient housing. Kadi and Lilius (2024) noted that social housing emphasizes the need for sustainable building practices to reduce long-term costs and improve living conditions for low-income households. This aligns with the findings by Stephens (2020) who argued that integrating energy-efficient designs in social housing can lead to significant cost savings and environmental benefits. Additionally, Dühr (2020) provided a comprehensive analysis of the financial barriers to implementing energy-efficient measures in social housing projects, suggesting that initial high costs can be offset by long-term savings in energy expenditures.

The role of government policies and subsidies is also crucial in this context. Studies by Wittowsky et al. (2020) and Stawarz et al. (2021) discussed the impact of governmental incentives on the adoption of energy-efficient technologies in housing. These studies indicate that subsidies and tax benefits can significantly lower the financial burden on investors, making energy-efficient social housing projects more viable. However, they also point out the need for continuous policy support to sustain these benefits over time. Moreover, the literature on the economic feasibility of social housing in other European countries provides valuable insights. For instance, Wijburg et al. (2024) explored the concept of socially responsible investment (SRI) in the context of housing, highlighting how ethical and environmental considerations can drive investment decisions. Their findings suggest that investors are increasingly considering the long-term sustainability and social impact of their investments, which could support the development of energy-efficient social housing.

Despite these advancements, there remains a notable gap in addressing specific requirements for achieving KfW energy standards in Germany, particularly concerning the combination of building elements like windows and their U-values (Ringel et al., 2022). The literature underscores the importance of a holistic approach to building design, integrating all elements to optimize energy efficiency (Stephens, 2020). Additionally, the economic analysis of insulation materials is crucial for achieving energy efficiency, with studies providing valuable data on the cost-effectiveness of various materials but needing more specific analysis related to KfW standards (Hasper et al., 2021).

3. METHODOLOGY

3.1. Basic Idea and Process

The primary objective of this study is to identify the financial framework necessary for constructing and operating energy-efficient social housing in Germany. The study aims to ensure that investors achieve reasonable returns on their investments and that tenants can afford the rent. The methodology involves detailed economic calculations and energy balance assessments for 45 realized mid-range residential buildings that meet EH 40 and EH 55 energy standards.

3.2. Data Collection and Sources

Data was collected from 45 residential buildings that have been realized and meet the EH 40 and EH 55 standards. These buildings were chosen based on the availability of comprehensive energy and financial data. The investment costs, including equity capital, subsidies, construction company profits, risks, and initial costs, were obtained from the funding applications submitted to the KfW Bank. Energy data was sourced from the energy certificates prepared for these buildings.

3.3. Energy Balance and Building Physics Calculations

The economic calculations for the buildings, which meet either the EH 40 or EH 55 energy standards, are based on energy certificates and confirmations of online applications with investment costs. Initially, all 45 buildings were calculated per DIN V 4108-6 (2003) for calculating annual heating and annual heating energy requirements and DIN V 4701-10 (2003) for heating, domestic hot water heating, and ventilation. The primary energy requirements were met using district heating with a low primary energy factor (fp < 0.25) in larger cities and air-to-water heat pumps with a COP of at least 3.8 in smaller cities or rural areas. The calculation methodology considers monthly losses and gains, with the heating requirement Qh specified as the balance between losses and usable (η) gains:

$$Q_h = (Q_t + Q_v) - (Q_s + Q_i) \quad (1)$$

Where:
- Q_t = Transmission heat losses
- Q_v = Ventilation heat losses
- ηQ_s = Solar gains
- Q_i = Internal heat gains

Better thermal insulation reduces Q_t while favorable window surface arrangement and construction methods affect ηQs. The study also considers the ratio of heat-exchanging surface area to volume, as smaller A-V ratios result in less heat loss. Assuming that the transmission heat losses Q_t can be reduced through better thermal insulation and the solar gains Qs through a favorable window surface arrangement and the heaviness of the construction method, there is essentially relatively little scope for influencing the two remaining parameters (ventilation heat loss QV and internal heat gains Qi). However, the transmission heat loss and the windows (with solar gains) have a high degree of connectivity to the costs. Added to this is the often neglected ratio of heat-exchanging surface area and volume. With small A-V ratios, the building loses less heat due to the cubature, which ultimately has an impact on the gross rental costs.

3.4. Economic Calculations

The economic analysis considers both income and expenditure to determine the net present value (NPV). The NPV relates all future payments to today's value, considering the base interest rate. The investment costs include building costs, land costs, profit margins, risk costs, and subsidies. The calculations were performed using the following equation computed using an R script:

The basis is the equation:

$$NPV = -investment + \sum_{i=1}^{N} \frac{netto\,cashflow(i)}{(1+s)^i} \quad (2)$$

Where:
- net cash flow (i) = Cash flows from income and expenditure during the investment period
- s = Base interest rate

If the equation is extended with the relevant parameters and rearranged to determine the required investment, the result is:

$$investment = -NPV + \left[rents(1+r)^i - interest\,component(i)\right](1-t) + \sum_{i=1}^{N} \frac{interest\,component(i) - principal\ \ component(i)}{(1+s)^i} \quad (3)$$

Where:
- r = Rent adjustment rate
- t = Income tax rate
- N = Repayment period
- interest component = Part of the annuity for which tax has to be paid
- principal component = Part of the loan to be repaid

The rent is increased annually by r%, while the cash flow in the denominator is discounted using the base interest rate (discount rate) s. The income tax t should take into account what proportion of the rent is available for refinancing. The annuity was calculated based on the investment costs for the 45 efficiency buildings analyzed. Equation 2 is solved for the investment if the NPV is zero.

This results in

$$investment = -NPV + \sum_{n=1}^{N} \left(\frac{[(rents(1+r)^i - i\_comp(i)] \\ (1-t) + i\_comp(i) - p\_comp(i)}{(1+s)^i} \right) \quad (4)$$

The interest component (*i_comp*) is the part of the annuity for which tax has to be paid and (*p_comp*) is the principal component. The investment is the total investment that must be made available to complete and operate the residential construction project, whereas the annuity only relates to the portion of the loan to be repaid, i.e. the residual debt.

Since the net present value (NPV) is assumed to be ≥0 to achieve profitability, the equation is simplified. If equation 4 is solved for the investment, and NPV is set equal to zero the result is:

$$0 \geq \sum_{i=1}^{N} \frac{\left[rents\left(1+r\right)^i - interest\,component\left(i\right)\right] \left(1-t\right) + interest\ component\left(i\right) - principal\ \ component\left(i\right)}{\left(1+s\right)^i} - investment \quad (5)$$

For the net present value to be zero, an investment is required to bring the project into economic equilibrium. This required investment must be provided by the investor.

To determine it, zero calculations are required, which use all the parameters interest rate s, rent adjustment r, repayment period N, annual rental income, taxes, and the required initial investment (R-script). The discount rate corresponds to the return on investment. To simplify matters, the income tax payments were assumed to be a flat rate of 0% and alternatively 25%. The equation then reads:

$$investment \geq \sum_{i=1}^{N} \frac{\left[rents\left(1+r\right)^i - interest\,component\left(i\right)\right] \left(1-t\right) + interest\,component\left(i\right) - principal\ \ component\left(i\right)}{\left(1+s\right)^i} \quad (6)$$

The following variables are considered in the analysis:
- Actual investment costs, gross: This includes all costs associated with the construction and development of the buildings, such as materials, labor, and overheads.
- Annual rent, net: The net rental income expected from the tenants, excluding additional costs such as utilities.
- Annual rent adjustment rate *r*: The expected annual increase in rent, reflecting inflation and market conditions.
- The interest rate for financing the loan interest component: The cost of borrowing funds to finance the construction, expressed as an annual percentage.
- The base or discount interest rate *s*: Used to discount future cash flows to their present value, reflecting the time value of money.
- The repayment to repay the loan principal component: The portion of the loan that is repaid annually.
- The financing/repayment period for the loan *N*: The duration over which the loan is to be repaid.
- Income tax rate *t* for sole financing of the project: The effective tax rate applicable to the rental income and other profits from the project.
- The year under consideration *i*: Each year within the investment period is considered to assess annual cash flows.

Furthermore, the living space and the number of residential units are available for the calculation of specific values. These values help in determining the per-unit investment, rent, and other financial metrics, ensuring that the analysis is grounded in practical, real-world scenarios.

The profitability calculations involved setting the NPV to zero and determining the required investment based on the given parameters. The relevant data for these calculations included actual investment costs, annual rent, rent adjustment rate, interest rate, base interest rate, repayment period, and income tax rate. The calculations aimed to achieve a balance between the investor's return on investment and the tenant's ability to afford the rent. The sensitivity analysis and profitability calculations provided insights into the impact of different parameters on the investment and rent levels, allowing for adjustments to ensure financial viability and affordability.

By incorporating these detailed methodologies, the study provides a comprehensive analysis of the financial and economic conditions necessary for the development of energy-efficient social housing in Germany.

3.5. Sensitivity Analysis

To understand the influence of various parameters on the investment and rent levels, a sensitivity analysis was conducted. Variables such as rent adjustments, discount rates, financing periods, and tax rates were varied, and their impact on required investments and initial rent levels was assessed. The following parameters were varied:
- Rent adjustment rate (*r*): 0-2%/annum
- Discount rate (*s*): 0-5%
- Interest rate: 0.3-10%
- Tax rate (*t*): 15-45%
- Financing period (*N*): 15-30 years

The effects of these parameters were observed and summarized in qualitative terms in Table 1.

Table 1: Qualitative effects of the parameters that are necessary from an ecological point of view for the realization of a construction project (multi-family houses)

Parameter	Investor	Tenant
Rents	Income from rents	Rent expenses
Rent increases	Increase revenues	Increase expenses
Interest rates	Increase expenses	Increase expenses
Interest rate advantages through the state	Reduce expenses	Decrease expenses
Base interest rate	Increases options (+1)	Increases expenses
Substitutions (−1)	decrease expenses	Decrease expenses
Tax benefits (−2)	decrease expenses	Decrease expenses
Corporate profits	increase revenue	Increase expenses
Construction costs	increase expenses	Increase expenses
Land charges	increase expenses	Increase expenses
Building quality	increase expenses (−3)	Increase expenses
Building quantity (Flat size)	increase revenue	Increase expenses
Reserves	increase expenses (+2)	Increase expenses (+2)
Psychological parameters	„is social" (+3)	„is equivalent to other higher earners"(+3)

(−1) Substitutions are to be financed by the general public and reduce the options to make other possibly more important investments.

(−2) Tax advantages reduce government revenues and thus the options to make other possibly more important investments.

(−3) Increases expenditure. However, this makes the building more sustainable as it lasts longer.

(+1) There are more options to make a more economical investment. For the tenant, this reduces the likelihood of getting an apartment.

(+2) But increases financial independence and mental well-being.

(+3) Fair, social, and ethical are terms that an investor can market effectively. Socially responsible investing SRI was recorded in figures in a paper (Berry and Junkus, 2013) and could also be used in the future as a seal such as a sustainable building, energy certificate, or noise certificate. The equivalent is to be seen here in the sense of equivalent living quality in terms of energy, as the buildings under consideration are efficiency houses.

3.6. Monte Carlo Simulations

Monte Carlo simulations were performed to analyze the effect of the influencing parameters on the monthly rent. A total of 10,000 simulations were conducted, varying the parameters within the specified ranges. The target variable was the monthly rent, and the results were used to determine the required investments under different scenarios.

The variance of the parameters was chosen as follows:

- Rent adjustment: 0% < r < 2%/a
- Discount rate: 0% < s < 5%
- Interest rate: 0.3% < ir < 10%
- Tax rate: 0.15% < t < 45%
- Finance period: 15 year < N < 30 yr

4. RESULTS

The results section provides a comprehensive analysis of the findings from the detailed economic and energy balance calculations for the 45 realized mid-range residential buildings that meet EH 40 and EH 55 energy standards. This analysis includes examining the real investments, specific investment costs, parameter variations, sensitivity analysis, and Monte Carlo simulations. The goal is to understand the economic conditions necessary for the development of energy-efficient social housing in Germany, ensuring a balance between financial viability for investors and affordability for tenants.

4.1. Real Investments

The real investments were taken from the confirmations for the KfW applications, which provided detailed cost breakdowns for the construction of the buildings. These costs encompass various aspects such as materials, labor, and overheads but exclude the costs for the land. To provide a comprehensive financial picture, the costs for the land were subsequently added based on a standardized land price of €500/m^2. This approach ensures consistency in the evaluation of investment costs across different projects.

The investment costs for the EH 55 category, which reflects the lower energy efficiency standard, were found to be approximately €1,122,684 (Figure 1). This figure represents the total expenditure required to achieve the EH 55 energy standard in the construction of mid-range residential buildings. On the other hand, the investment costs for the EH 40 category, which corresponds to a higher energy efficiency standard, were approximately €1,281,072 (Figure 2). The higher costs associated with EH 40 are indicative of the additional investments needed to meet more stringent energy performance requirements, which include better insulation, advanced heating systems, and other energy-saving measures.

4.2. Specific Investment Costs

When the investment costs are related to the energy reference area (ANGF), a detailed analysis reveals specific cost ranges for both the KfW-55 and KfW-40 houses. For the KfW-55 houses, the investment costs range from €1,102/m^2 to €2,528/m^2. This broad range reflects the variability in construction costs due to factors such as building design, material quality, and regional construction market conditions. The lower end of the range typically includes buildings with standard features and materials, while the higher end includes those with premium features and higher-quality materials.

For the KfW-40 houses, the investment costs are slightly more concentrated, ranging from €1,149/m^2 to €2,197/m^2. This range is narrower compared to the KfW-55 houses, which can be attributed to the more stringent energy efficiency requirements that necessitate consistent high-quality materials and construction practices. The investment costs at the lower end of this range reflect efficient planning and cost management, whereas the upper end represents investments in advanced energy-saving technologies and superior construction quality.

To ensure the reliability of these cost estimates, the statistical data for these categories were analyzed. The distribution of the investment costs was evaluated using the Shapiro-Wilk test, a well-regarded method for assessing normality. The results of the Shapiro-Wilk test indicated a W value close to 1, suggesting that the data closely follows a normal distribution (Table 2). Additionally, the $P > 0.05$, confirming that there is no significant deviation from normality. This statistical confirmation of normal distribution provides confidence in the representativeness of the cost ranges and supports the validity of the conclusions drawn from this analysis. The statistical parameters shown in Table 2 are based on a previous simulation and investment analysis by the authors.

Table 2: Statistical data of the analyzed efficiency building categories

category	mean	sd	median	iqr	min	max	cv	skew- ness	kurtosis	shapiro_ wilk_w	shapiro_ wilk_p
EH 40	1672.6	524.0	1752.1	729.8	829.8	2607.3	0.313	0.030	2.062	0.968	0.585
EH 55	1815.0	713.3	1861.5	674.6	542.2	3408.7	0.393	0.579	3.063	0.953	0.416

Figure 1: Distribution of real investments for the KfW-55 category

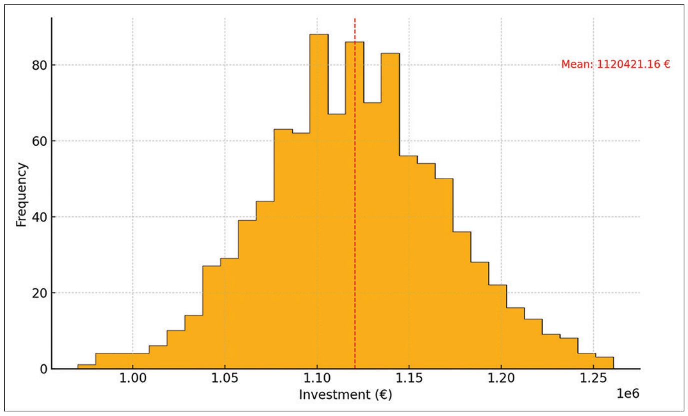
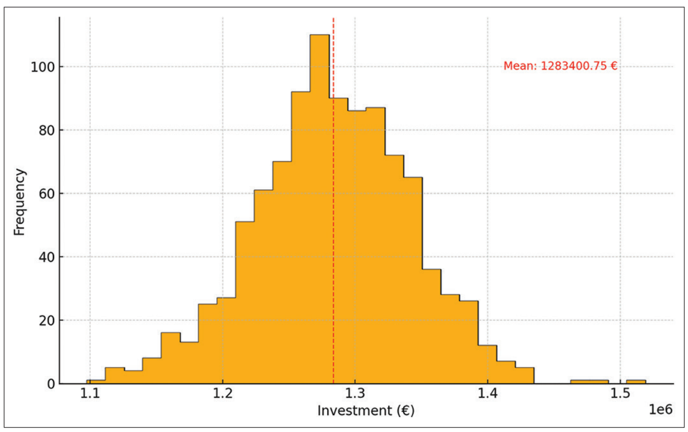


Figure 2: Distribution of real investments for the KfW-40 category



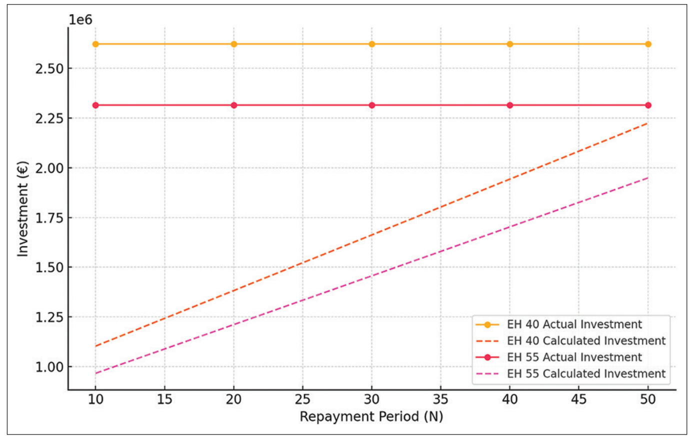
While the original simulation parameters are no longer available in detail, the tabulated results represent validated outcomes used consistently throughout this study.

4.3. Parameter Variations

The influence of different parameters on the required investments was analyzed in detail to understand their impact on the financial feasibility of constructing energy-efficient buildings. Various factors such as rent adjustment rate, interest rate, investment period, and tax rate were varied while keeping all other variables constant (ceteris paribus) to isolate the effect of each parameter. The most frequently occurring investment values were identified to establish a baseline for comparison (Figure 3).

These parameter variations were systematically adjusted until the calculated investment closely matched the actual investment figures, ensuring that the net present value (NPV) of the investment was zero. This approach provided a clear understanding of how changes in each parameter affect the overall investment cost. The analysis aimed to identify the optimal conditions under which the investments would be financially viable, balancing the need for energy efficiency with cost-effectiveness. This rigorous process

Figure 3: Comparison of actual versus NPV investments by KfW category



highlighted the sensitivity of the investment costs to various financial and economic factors, providing valuable insights for policymakers and investors. The lowest deviations are observed with a repayment period of 40 years. The deviations are due to various factors, including the coronavirus crisis, which led to price increases for building materials and construction services (Table 3).

4.4. Sensitivity Analysis

The sensitivity analysis was conducted by varying four key parameters: Rent adjustment rate (r), base interest rate (s), investment period (N), and tax rate (t). The influence of these parameters on the required investments was observed and depicted in Figure 4. Changes in the rent adjustment rate (r) significantly impact the required investments, with higher rent adjustments necessitating more initial investment, increasing by €1,200,000 for a 2% adjustment. The base interest rate (s) has a substantial influence as well, with higher interest rates (ranging from 0% to 5%) reducing the present value of future income, thereby lowering the required initial investment by €1,100,000. Extending the financing period (N) from 10 years to 50 years increases the initial investment by €900,000 due to higher total interest payments over time. Additionally, higher tax rates (t) from 15% to 45% reduce net returns, requiring an additional €500,000 in initial investments to maintain financial viability. These findings highlight the critical importance of carefully managing these parameters to balance investment costs and ensure the financial feasibility of energy-efficient social housing projects.

4.5. Monte Carlo Simulations

Monte Carlo simulations were performed to analyze the effect of the influencing parameters on the monthly rent. A total of 10,000 simulations were conducted, varying the parameters within specified ranges, including rent adjustment rate (0-2%), base interest rate (0-5%), financing period (10-50 years), and tax rate (15-45%). The results, depicted in Figure 5, show a wide distribution of possible monthly rents, reflecting the significant impact of these variables. The histogram reveals that most

Figure 4: Required investments when changing variables

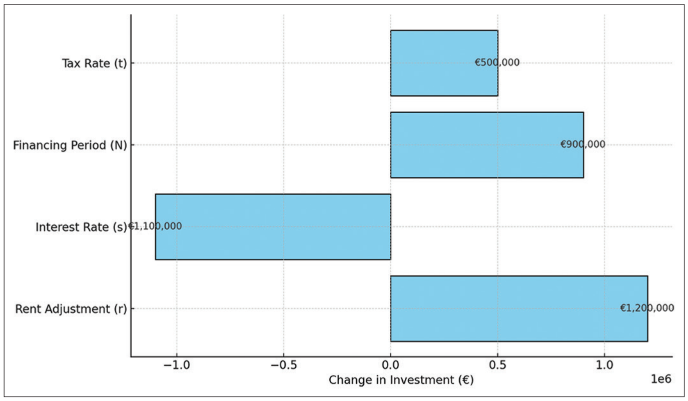
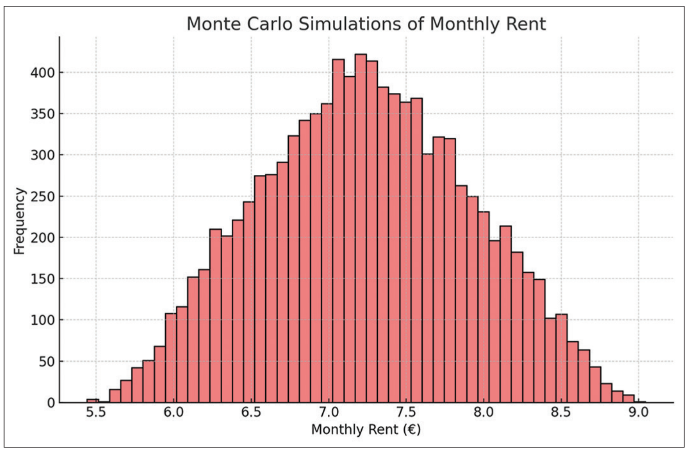


Figure 5: Monte Carlo simulations



simulations resulted in monthly rents clustering around a certain range, with the most frequent outcomes centered between €700 and €1200. This distribution highlights the variability and potential uncertainty in monthly rent calculations due to changes in key financial parameters. The analysis indicates that base interest rates and rent adjustment rates are particularly influential, with higher interest rates leading to increased monthly rents, while longer financing periods help to moderate the rental costs (Table 4). These findings underscore the importance of carefully managing financial parameters to achieve balanced and sustainable rent levels in energy-efficient housing projects.

The simulations show that the discount rate has the greatest influence on the initial rent, with almost one euro per square meter for a 1% increase in interest rates. The tax rate has a monthly impact of +€0.60/m^2 for a 5% increase in taxes.

4.6. Summary of Observations

- Rent adjustment rate (r): Higher rental increases lead to lower initial rents as investors expect higher future income.
- Base or discount rate (s): Higher discount rates reduce the present value of future income, requiring higher initial rents.
- Financing or repayment period (N): Longer repayment periods reduce the annual burden, allowing for lower initial rents.
- Tax rate (t): Higher tax rates reduce returns, necessitating higher initial rents.

Table 3: Deviations of actual and calculated investments of EH 40 and EH 55 in relation to payback period N

Category	Actual investment (€)	Calculated investment (€)	Deviation (%)
EH 40	2,621,814	1,103,571	138
EH 55	2,314,535	967,128	139
EH 40	2,621,814	1,382,432	90
EH 55	2,314,535	1,211,512	91
EH 40	2,621,814	1,662,143	58
EH 55	2,314,535	1,456,640	59
EH 40	2,621,814	1,942,538	35
EH 55	2,314,535	1,702,368	36
EH 40	2,621,814	2,223,454	18
EH 55	2,314,535	1,948,552	19

Table 4: Rents calculated with Monte Carlo simulation

Parameter	Intercept	Slope	Step	Change per step (€)
Rent adjustment r	9.95	−9.398	0.005	−0.47
Discount rate s	6.63	9.438	0.01	0.94
Payback period N	16.73	−0.035	1.000	−0.35
Tax rate t	6.45	1.196	0.050	0.60

These findings suggest that adjusting these parameters can help balance the financial interests of investors and the affordability of rents for tenants. The detailed analysis provides a comprehensive understanding of the economic conditions necessary for the development of energy-efficient social housing in Germany.

5. DISCUSSION AND CONCLUSION

The economic feasibility of constructing energy-efficient social housing has been a topic of interest, yet gaps remain in understanding the detailed financial conditions necessary for such projects in Germany. While previous studies have focused on the physical and environmental benefits of energy-efficient buildings, few have explored the intricate financial dynamics that influence both investors and tenants. This study addresses this gap by examining the economic conditions required to achieve affordable rents in social housing while meeting EH 40 and EH 55 energy standards.

This study analyzed 45 mid-range residential buildings to determine the economic conditions necessary for energy-efficient social housing in Germany. Key findings reveal significant variability in investment costs, with EH 40 buildings requiring approximately €1,281,072 and EH 55 buildings needing about €1,122,684. Sensitivity analysis identified rent adjustment rates, base interest rates, financing periods, and tax rates as critical factors affecting investment viability. Monte Carlo simulations demonstrated the variability in monthly rents, with most values clustering between €700 and €1200, highlighting the influence of these financial parameters on rental costs.

Our findings align with previous research on the economic benefits of energy-efficient housing, such as those by Shahad et al. (2021) and Galvin (2023), which emphasize the cost savings from improved building designs. The higher investment costs for EH 40 buildings are consistent with the need for advanced energy-saving technologies. The sensitivity analysis showed that rent adjustment rates and base interest rates substantially impact required investments, corroborating studies by Galvin (2024) and Taruttis and Weber (2022). These results suggest that careful financial planning can significantly affect the economic feasibility of energy-efficient social housing projects.

Moreover, the findings from our Monte Carlo simulations are in line with the work of Medved et al. (2020) who highlighted the variability in financial outcomes due to changes in key economic parameters. Our study extends this by specifically focusing on the rental market for energy-efficient social housing, showing that factors such as interest rates and rent adjustment rates can lead to significant fluctuations in monthly rents. This variability underscores the importance of incorporating robust financial models and risk assessments in the planning stages of such projects. Additionally, our results support the conclusions of Ringel et al. (2022) which advocates for sustainable building practices to reduce long-term costs and improve living conditions for low-income households. These comparisons highlight the broader applicability of our findings and reinforce the necessity for strategic financial management in the development of energy-efficient social housing.

Several limitations must be acknowledged in this study. The reliance on historical data from 45 specific residential buildings may not capture the full range of construction practices and costs across different regions and building types. Additionally, assuming a standardized land price of €500/m^2 might not reflect actual land prices everywhere. The economic calculations did not account for potential future changes in government policies or economic conditions, which could impact investment and rent levels. These limitations suggest that while the findings are robust, they should be interpreted with some caution.

Future research should expand the sample size to include a broader range of building types and regions to enhance the generalizability of the findings. Studies should also consider dynamic changes in government policies and economic conditions to provide more robust financial planning models. Additionally, exploring the integration of renewable energy sources and their impact on investment and operational costs could further improve the sustainability and economic viability of social housing projects. Advanced statistical methods should be implemented to account for regional variations and market conditions, offering more accurate and comprehensive insights.

In conclusion, this study highlights the critical role of financial planning, government policies, and strategic investments in developing energy-efficient social housing in Germany. The findings emphasize the need for a comprehensive economic strategy to balance investment costs and ensure the financial feasibility of these projects. By carefully managing key financial parameters such as rent adjustment rates, base interest rates, financing periods, and tax rates, policymakers and investors can achieve sustainable and affordable housing solutions. This research provides valuable insights for future studies and policy development aimed at promoting energy-efficient and economically viable social housing initiatives.

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